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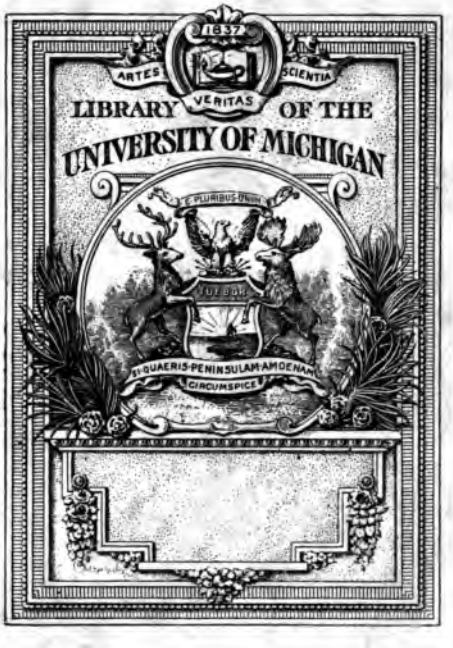
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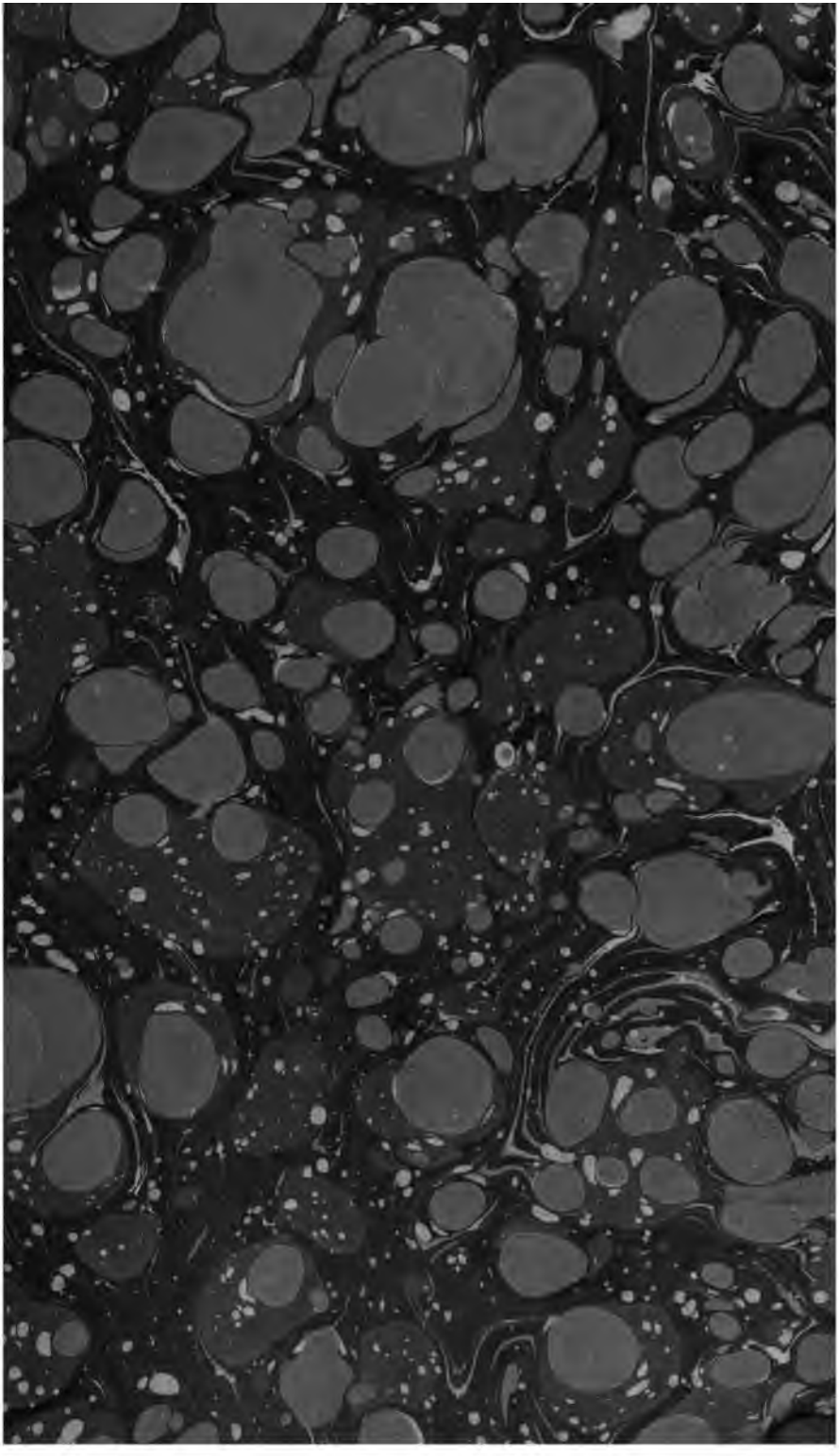

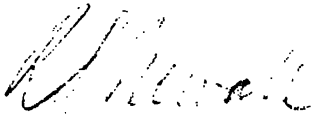

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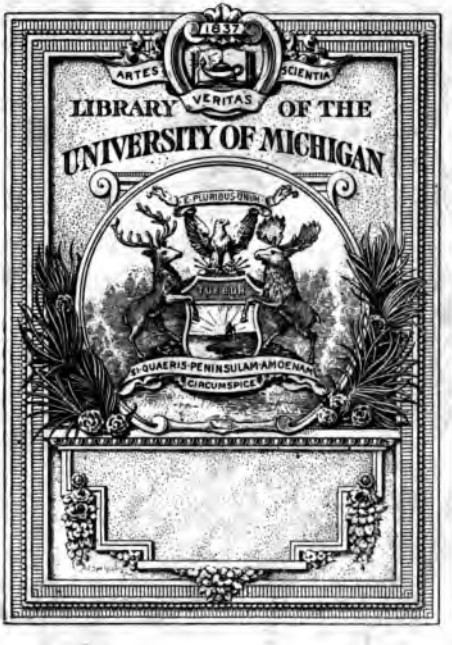
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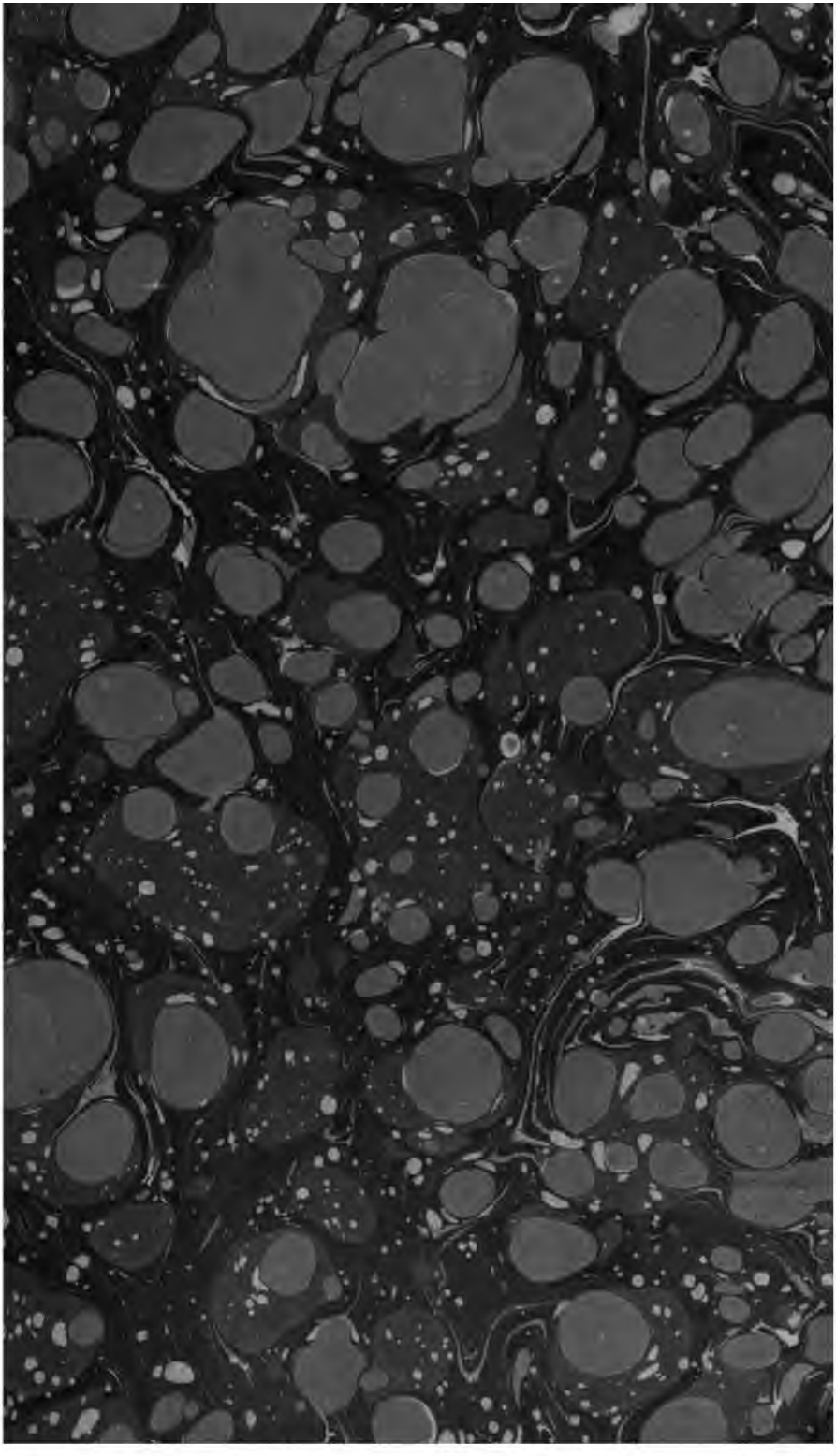

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MEMOIRS

OF THE

Literary and Philosophical Society of Manchester.

I.—*An Account of the Early Mathematical and Philosophical Writings of the late Dr. Dalton.*

By T. T. Wilkinson, F.R.A.S., &c.

[*Read October 18th*, 1853.]

The miscellaneous mathematical and philosophical writings of the late Dr. Dalton extend over a period of many years, and lie scattered in the pages of several periodicals issued at intervals towards the close of the last century. Their nature and their existence are almost alike unknown to the majority of the present generation; nor is it too much to assert, that many of those who admire and appreciate his subsequent writings and discoveries, possess little or no information as to the means by which he was enabled to attain his high position in the world of science. His earliest efforts were directed towards the solution of a few simple questions in mathematics and natural philosophy; but, aided by the advice of his friends, and encouraged by the editors of those great promoters of self-exertion, the *Ladies'* and *Gentleman's Diaries*, he rapidly succeeded in establishing his reputation as an accomplished mathematician and philosopher. The object of the present paper is to rescue a portion of these interesting

opuscula from oblivion, and to trace the steps by which he qualified himself for the development of the theory of definite proportions;—the attempt must necessarily be imperfect, but it is hoped that, notwithstanding its defects, it will be favourably received by that society of which its subject was so long the distinguished ornament.

The late Dr. Dalton commenced his career as a philosopher and mathematician in the *Gentleman's Diary* for 1783. He was then in the seventeenth year of his age, and for about two years previously had held the situation of usher in a school conducted by his cousin, Mr. George Bewley, at Kendal. The construction of triangles from given data engrossed a considerable share of the attention of English geometers at this period, and algebraical and geometrical solutions to two questions of this class formed the subject of Mr. Dalton's first communication to this Diary. Neither of these solutions, however, had the good fortune to obtain insertion at length, but his name is preserved amongst those whose investigations had been found to be correct, whilst the nature of the questions themselves afford good evidence that he had already begun to profit by the advice and instruction of his friend and tutor, the late Mr. John Gough.* In 1784 Mr. Dalton's name appears amongst those who answered the prize enigma in the *Ladies' Diary* for that year, and he also

* Many of Mr. Gough's pupils have taken high degrees at Cambridge or become otherwise distinguished. At different periods Dr. Whewell, Master of Trinity, obtained the position of *second* wrangler; Mr. Dawes, Tutor of Downing College, that of *fourth* wrangler; Mr. King, Tutor of Queen's College, became *senior* wrangler; and Mr. Gaskin, Tutor of Jesus College, *second* wrangler;—all of whom were formerly under his tuition. Mr. Gough was also an extensive contributor to the mathematical periodicals, and several of his Memoirs on Natural Philosophy, &c., may be seen in the early volumes of the Memoirs of this Society.

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* "Par *l'analyse*, on regarde comme vraie la proposition que l'on veut dèmontrer, ou comme résolu le problème proposé, et l'on marche de conséquence en conséquence, jusqu'à ce qu'on arrive á quelque vérité connue, qui autorise à conclure que la chose admise comme vraie l'est réelement, ou qui comporte la construction du problème ou son impossibilité.

"Par la *synthèse*, on part de vérités connues pour arriver, de conséquence en conséquence, à la proposition que l'on veut démontrer, ou à la solution du problème proposé."—(*Chasles, Géométrie Supérieure, Discours*, p. 40.)

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ancient geometrical analysis was much cultivated by Lawson, Crakelt, Wildbore, and others, and the editors of our mathematical periodicals vied with each other in their endeavours to obtain purely geometrical solutions to all questions supposed to admit of this method of procedure. Mr. Dalton does not seem to have been sufficiently aware of this desire on the part of the conductors of those periodicals to which he contributed, and hence we have another reason, besides inexperience, for the failure of many of his juvenile efforts. On almost every occasion his early *algebraical* solutions had to give place to the purely *geometrical* ones furnished by more experienced correspondents. But Mr. Dalton's ambition was not of that uncertain character which quails at difficulties and relapses into indifference when confronted with neglect:—"perseverance overcomes every obstacle" was a motto he had learned in early youth, and when he renewed his attempts to obtain a place in the "pages of the imperishable Diary," he had so far improved his opportunities of acquiring information that success was almost certain. The selection of questions for the year 1787 embraced nearly all the branches of mathematics then cultivated by English geometers, and yet he correctly solved *thirteen* out of the list of *fifteen*, the prize question included. His solution of question 850 is inserted at length in the Diary as having been furnished by "Mr. John Dalton, teacher of mathematics in Kendal," and is probably the earliest printed specimen of his mathematical writings.

Mr. Dalton, however, did not confine himself to mathemamatics alone. At the early age of twenty-two he had turned his attention to chemistry, and was already conversant with several French authors on that subject. In the *Ladies' Diary* and *Supplement* for 1788 he favours the editor with his opinions on the "composition of India rubber, or elastic gum;" some "account of which," he observes, "may be seen

in some late elements of chemistry written in French." With regard to Query 3, he urges that "the reason why the sun, shining upon the fire, renders it so languid, seems to be owing to its rarefying the circumambient air; for it has been proved, from a variety of experiments by Boyle and others, that combustible bodies burn with more or less vehemence, as the air they are in is condensed or rarefied." In answer to Query 4, he cites the *Scriptures*, *Aulus Gellius*, and *Chambers's Cyclopædia*, in proof of the antiquity of the use of the ring in marriage, and also when conferring particular honour on individuals. "The Greeks," he observes, "always wore the wedding ring on the *fourth* finger of the *left* hand," and the reason for it is, "that having found from anatomy that this finger had a little nerve which went straight to the heart, they esteemed it the most honourable by reason of this communication with that noble part." His correspondence to the mathematical department of this Diary is somewhat extensive. He answers *thirteen* questions out of the *fifteen* proposed, and is so far successful as to have three of these inserted at length. The first solution corrects several errors in Hawney's Mensuration, relative to regular polygons; the second affords sufficient evidence that mechanics and fluxions had engaged his attention; whilst the third appears worthy of transcription, in proof that the higher branches of natural philosophy had at this time been cultivated by him with success. During this year he also proposed the following questions for solution, the latter of which forms Question 593 of the *Gentleman's Diary*, at this time under the able management of the Rev. Charles Wildbore, who, under the signature "Eumenes," supplies an elegant geometrical solution to Mr. Dalton's question:—

Ladies' Diary, 1788. *Question* 884. *By Mr. John Dalton.* "In the semicircle ACB, whose diameter is AB, and OC perpendicular to it from the centre, from B there is

drawn a chord BF to cut OC in E, and on the same chord there is taken BD equal to the radius of the semicircle;—it is required to determine the rectangle DE.EF, a maximum."

Ans. BD = 1; DE = ·1974; EF = ·4731.

Gentleman's Diary. Question 593. *By Mr. John Dalton.* "From a given circle to cut off an arc, such, that the rectangle under its versed sine, and the cosine of its double may be a maximum."

Ladies' Diary. Question 875. *By Mr. Alexander Rowe.* "It is required to find the diameter of a circular parachute, by means of which a man of 200 pounds weight may descend from a balloon at a great height, with the uniform velocity of only 10 feet in a second of time; the parachute being supposed to be made of such materials and thickness that a circle of it 50 feet diameter weighs only 150 pounds."

Answered by Mr. John Dalton. "If a falling body move with a uniform velocity, it must necessarily meet with a resistance, in the medium it is moving in, equal to its weight. Now it has been proved (*Emerson's Mechanics, prop.* 108, *cor.* 3) that the resistance to a cylinder, moving in a fluid in the direction of its axis, is equal to the weight of a cylinder of that fluid of the same base, whose length is equal to the height a body falls *in vacuo* to acquire its velocity. Put now $g = 32\frac{1}{6}$ feet, v = the velocity; then $g^2 : v^2 :: \frac{1}{2}g : \frac{v^2}{2g}$ = the altitude fallen to acquire the given velocity. Call this altitude a, and put also $p = \cdot 7854$; $b = \cdot 075$lb. = the weight of a cubic foot of air; $m = 200$lbs. = the man's weight; also x = diameter of the parachute. Then $50^2 : x^2 :: 150 : \frac{3}{50}x^2$ = weight of the same; which added to 200 or m, must be equal to the resistance. That is $\frac{3}{50}x^2 + m = a\,b\,p\,x^2$; and hence $x = 100\sqrt{\frac{2g}{375p - 6g}} = 80\frac{5}{8}$ feet nearly, the diameter sought."

On the appearance of the *Ladies' Diary* for 1789, Mr. Dalton must have felt himself amply rewarded for all his

previous disappointments; for, besides obtaining insertion of his answers to *all* the philosophical queries, and to *three*, out of *eleven* solutions sent to the questions in the mathematical department, he was awarded the "prize of six Diaries," for his answers to the queries, rebusses, &c., proposed in the Diary for 1788. In the *first* query he discusses the reasons "why sound is more distinct at night than in the day time." "The air," he observes, "is calm, and nature is composed. * * * * Add to this, that probably the mind may be more attentive than ordinary to ideas of sound at that time, when the faculty of vision is in a great measure suspended for want of light." The answer to the *second* query accounts for the "singing of the tea kettle," on the ground that the metal containing the water varies in temperature. "That part of the kettle which is in contact with the water being much cooler than the remaining portion, and the steam rising against it, will be continually dissipated with a hissing sound like that made by immerging hot iron in water." In the answer to the *third* query he considers the law of divorces, and is of opinion "that the marriage state would not be rendered happier were divorces much more easily obtained. * * The condition of the female sex in general would evidently be greatly depressed by such facility. * * * * And anything that has a tendency to lessen the dignity of the fair sex, in [his] opinion, is unlikely to increase the happiness of the marriage state." The *fourth* query relates to the subject of living toads having been found in solid rocks. Mr. Dalton considers "that a just and satisfactory account of these astonishing phenomena can hardly be expected in the present state of philosophy;" but after referring to the *Philosophical Transactions* and the *Memoirs of the Academy of Sciences* for similar facts, he conjectures that the animals had entered the rocks when these were yet "in a soft state, * * * * [and] petrifaction going on, have been so firmly imbedded as

not to be able to escape; * * * * we may suppose [therefore] that being destitute of food and air, the vital functions will remain suspended, * * * * till, by accident, being delivered from their imprisonment, they recover from their torpid state." The answer to the *fifth* query relates to a subject upon which Mr. Dalton had already begun to collect special information. In 1788 we find he had commenced a series of experiments and observations which led to the publication of his *Meteorological Essays*, in 1793, and hence we need not be surprised at meeting with some truly philosophical reasons why the "air [feels] colder about the times of sunrise and sunset than either before or after." He remarks that "the temperature of the air, in clear, serene weather, as determined by the thermometer, is generally as follows:—The greatest cold in the twenty-four hours prevails at or a little before sunrise; from thence till about two in the afternoon the heat gradually increases, and afterwards gradually decreases, till next morning;—which may be accounted for thus: the clear air, affording a free passage for the sun's rays, like other transparent bodies, receives very little heat from them. Of course, then, its heat must be chiefly derived from the surface of the earth, which, being acted on by the sun's rays, will constantly communicate its heat to the adjacent air; so that as the surface gradually increases in heat from sunrise till sometime afternoon, and then decreases in the same manner, so will the air also that is near it." At the conclusion of his answer, "the ingenious querist" is reminded, that if he "have frequently found it colder about sunset than afterwards, he must have judged of the temperature from sensation, and not from a thermometer;"—a remark, by the way, which, independently of its quiet humour, furnishes an excellent practical method of disproving many a popular fallacy. The proposer of the *sixth* query desires to be informed, "what system of philosophy

gives us the most convincing proofs of the immortality of man;" and he is very properly assured by Mr. Dalton, in the *Diary Supplement*, that "the existence of man in a future state rests only on probability, from any system of philosophy hitherto known. Contemplative men," he adds, "of all ages, but more especially since the modern improvements in philosophy, might reasonably imagine that the Divine Being whose bounty is not less conspicuous than his power and wisdom, would not have endued men with faculties capable of such vast improvements, had they been designed to finish their existence with this life. But notwithstanding this, there might still have been room for doubt, had we not been assured from Revelation that the present life is only preparatory for another of endless duration."

In the mathematical portion of this Diary his solution to question 882 relates to the vibration of a second's pendulum at the distance of four radii from the earth's centre; that to question 885 discusses a case of equilibrium proposed by Mr. Wildbore, under the signature "Amicus;" and the solution to question 886, inserted in the Supplement, and since transferred to Professor Leybourn's edition of the Diaries, enables the reader to set at rest a controversy on the *true* rule for equation of payments, with which Mr. Thomas Todd agitated the mathematical world at intervals for almost half a century. But the preceding did not constitute the whole of his contributions to the periodicals for this year. In the *Gentleman's Diary* his name is announced as having furnished correct solutions to *seven* of the mathematical questions, of which that to question 591, relating to a case of hydrostatical equilibrium, is inserted at length, and gained him his first position amongst the correspondents to this noted and difficult serial.

The *Ladies' Diary* and *Supplement* for 1790 must again have been peculiary satisfactory to Mr. Dalton;—for besides

containing his answers at length to *three* of the queries, and also to the same number of the mathematical questions, they conveyed the gratifying intelligence that he had been awarded the highest "Prize of ten Diaries" for his masterly solution of the prize question. The answer to the *first* query is printed in the Supplement, and inquires whether "it is possible for two persons of opposite sexes to hold a strict friendship with each other without some degree of love." Mr. Dalton maintains the affirmative, provided "the ardour of youth is moderated by time, and reason and religion have reduced the passions into due subordination." The answer to the *second* query appears in the Diary itself. It relates to the *red* appearance of the atmosphere as indicative of approaching wind or rain, when seen in the morning, or of fair weather, when seen at sunset. Mr. Dalton admits that "the observation in the query is perhaps as well founded as any in meteorology, * * * * * but with regard to the *cause* [he is] afraid nothing but *hypotheses*, unsupported by facts, can be advanced, as our philosophy of the atmosphere is yet only in its infancy. There need, however, be no wonder that *similar* appearances in the evening and morning are followed by *different* consequences, as the air at the former time is generally in a cooling state, and in a heating one in the latter." His remarks on the *fifth* query are found in the Supplement, from which it appears he considered "the act of yawning, with numerous other involuntary acts of the like nature, to proceed from that distinguishing feature of humanity, *sympathy*." A considerable variety of answers to this query are furnished by the correspondents to the Diary, most of which agree in principle with the preceding, and the editor adds "a remarkable instance" to the number, in consequence of his having been "seized with an extraordinary fit of yawning while writing out most of the solutions."

In the mathematical department he answers *ten* out of the list of *fifteen* questions proposed, of which those to questions 5, 11, and 15 obtained insertion. The fifth question relates to the impact of two elastic bodies;—the eleventh to the flow of water through a circular aperture;—and the solution of the prize question is here transcribed as furnishing an interesting specimen of his attainments in physical astronomy.

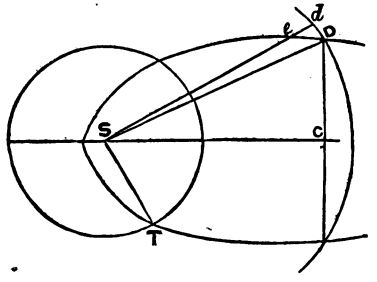
Prize Question, 907. *By Lieut. William Mudge.* "It is required to determine the quantity of heat received by the great comet, expected to appear in the beginning of the year 1789, during its passage from the aphelion to its perihelion, the quantity received in one second when at the mean distance of the earth being given = q; and to compare the mean heat of the earth to the greatest heat of the comet when in its perihelion; the period of the comet being 128¼ years, and its perihelion distance ·44851, the radius of the earth's orbit being unity."

Answered by Mr. John Dalton. "Lemma 1. Suppose two like bodies to revolve round the sun in concentric circles; then the quantities of heat received by each body in one revolution will be inversely as the square root of their distances from the sun. For let H and h be the quantities received in any small given time, as one second; T and t their periodic times in seconds; R and r their distances from the sun. Then as the density, and consequently the heat of the solar rays, is inversely as the square of the distances from the sun, it will be $H : h :: r^2 : R^2$; and it is well known that $T : t :: R^{\frac{3}{2}} : r^{\frac{3}{2}}$; and, therefore, $TH : th :: r^{\frac{1}{2}} : R^{\frac{1}{2}}$.

Lemma 2. Suppose two like bodies to revolve round the sun, the one in a circle and the other in an ellipse, whose transverse axis is equal to the diameter of the circle; then the quantities of heat received by each in one revolution will be inversely as the areas of their orbits. For let the orbits be as in Fig. 1, and draw SD and S *e d* indefinitely near it; then

since the velocities of the two bodies when at D are equal (*Principia Lib.* 1, *prop.* 16, *cor.* 4), the times of describing, and, consequently, the heat acquired in D*d*, D*e*, will be as D*d*: D*e*; that is, from similar triangles, as DC : SD, or as the area of the ellipse to the area of the circle. But the whole quantities received in one revolution are as the quantities received in the ∠ DS*d*; therefore the truth of the lemma is evident.

Fig. 1.



Solution. "To determine the comet's orbit from the data and the laws of centripetal forces, it will be as $1^2 : 1^3 :: (128\frac{1}{4})^2$: cube of the semitransverse axis of its orbit = 25·4314769 = a; and the eccentricity = semitransverse — perihelion distance = 24·9829669 = b; from which the conjugate axis = 4·755142 = c;—then from the first lemma it will be as $\sqrt{a} : \sqrt{1} :: sq : sq \div \sqrt{a}$ = the heat which would be received by the comet in one revolution round the sun in a circle whose diameter = transverse axis of its orbit, where s denotes the number of seconds in a year. But, by the second lemma, $c : a :: sq \div \sqrt{a} : sq\sqrt{a} \div c$ = the heat received by the comet in one revolution in its proper orbit; half of which = 16733512 q = the quantity of heat received in its passage from aphelion to perihelion, as required. Also, the heat of the comet in perihelion will be to the mean heat of the earth as 4·97113 : 1, nearly." A second solution, by Mr. Dalton, "without the lemmas," is also inserted in this Diary, but since it merely confirms the accuracy of the preceding general expression for the heat, it need not be added.

In the *Gentleman's Diary* for the same year his contri-

butions are equally meritorious and interesting. His name is appended to *sixteen* out of the *seventeen* questions proposed for solution, and as most of them are of a difficult character, we may safely infer that even at this period he had few superiors among his contemporaries in mathematics and natural philosophy. His ability in pure geometry and in the discussion of loci appear very conspicuously in the solutions furnished by him to questions 7 and 15 in this Diary, and in several succeeding numbers we shall find him equally conversant with some of the most difficult branches of dynamical inquiry. Question 10, in the selection for this year, is the celebrated question respecting the exciseman's staff,* which led to an interesting controversy between Mr. Wildbore and Mr. James Wolfenden, of Hollinwood, near Manchester. Mr. Dalton, in common with other correspondents to the Diary, had solved the question on the supposition that the staff exerted *no pressure on the edge of the vessel;* but this supposition was proved by Mr. Wolfenden, in the *Mathematical Companion*, to be incorrect, and the freedom of his criticisms led Mr. Wildbore to combat several of his conclusions, but without success. More recently the discussion has been revived in the pages of the *Mechanics' Magazine*, where the able investigations of Tebay, Workman, and Indagator have apparently set the question at rest, and confirmed the general accuracy of Mr. Wolfenden's results. The editor of the *Gentleman's Diary* evidently considered his scientific reputation at stake, and by means of his correspondents con-

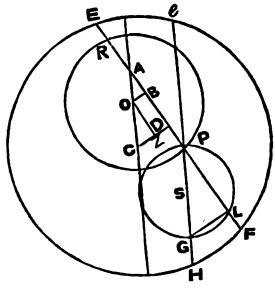
* *Question* 609. *By Mr. John Fletcher.* "Seeing an exciseman's staff in the form of a cylinder, three-fourths of an inch in diameter and 36 inches long, immersed in a vessel of beer at one end, and the other resting upon the edge of the vessel, 3 inches above the liquor, I observed 13 inches along the staff to be dry;—required the weight of the staff, the specific gravity of the beer being supposed to be known."

tinued for several years to propose variations of the original problem, in the hope that some fortunate result would be developed which would enable him to silence his opponents. Mr. Dalton, however, does not appear to have taken any part in the dispute:—he was ever averse to controversy under any circumstances, and although a confirmation of his results was offered by the editor in the Diary for 1799, he did not choose to enter the lists in favour of the erroneous principle. His solution of question 7 in this series may be selected as affording a neat specimen of his method of treating a geometrical locus.

Question 606. *By Mr. John Fletcher.* "If through any point P in the periphery of a circle, that is wholly included in another, an indefinite number of right lines be drawn to cut the periphery again in R, and terminate in the circumference of the greater circle in E and F, and from E towards F there be always taken EL = RF; required the locus of the point L."

Answered by Mr. John Dalton. "From the centres C and O let fall CD and OB perpendicular to *any* right line FPE drawn as per question. Then since DR = DL, and BR = BP, therefore PL = 2BD; through P draw a line parallel to OC, on which set off PG = 2OC; then will G be a point in the curve the farthest possible from P. Join GL and let fall O*l* perpendicular to CD;—then since the angle CO*l* = GPL and the including sides CO, *l*O, just half the sides PG, PL, the triangles are similar, and the angle PLG = a right angle. Consequently the required *locus* of L is a circle whose radius PS = CO."

Fig. 2

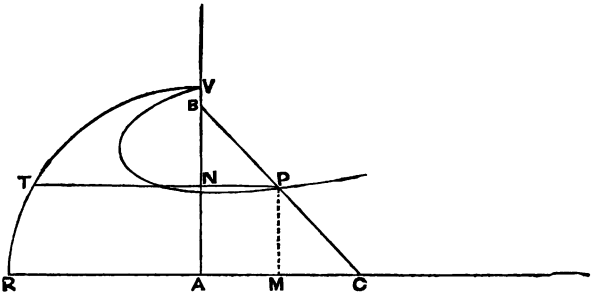


In the *Ladies' Diary* for 1791, Mr. Dalton entirely confined himself to the mathematical department. He furnished solutions to *eleven* of the questions, and obtained insertion of those to the *first*, *ninth*, and *fourteenth* of the series. His name also frequently occurs in the *Diary Supplement* for this year, but its pages are wholly occupied by the communications of other contributors. The first solution in the Diary relates to the determination of x and y from two given equations, which Mr. Dalton concludes is impossible in *whole* numbers; the second furnishes an elegant determination of "the *least* breadth of a new cut, at right angles to a river, so as to admit of the passage of a given barge;" and the third produces an *exception* to a property in the theory of equations which the proposer, Mr. Bonnycastle, had been led to consider general. To the *Gentleman's Diary* for the same year he contributed twelve solutions, but the only one which obtained insertion at length is that to the following difficult locus which had been proposed by himself in the previous Diary.

Question 631. *By Mr. John Dalton.* "Suppose two bodies B and C to set off together from a point A, and move along two right lines at right angles to each other, the one B with a uniform velocity, the other C with a velocity such, that the space described may be as *any* power of the time;—also suppose a line BC to be drawn between the bodies, and CP taken thereon equal to a given line. Required the equation and quadrature of the curve which is the *locus* of the point P."

Answered by Mr. John Dalton. "Suppose PM perpendicular to AC and PN to AB; put s and c for the spaces described by the bodies B and C respectively in one second at the beginning. Put $CP = b$; $AN = x$; $PN = y$; $AC =$

Fig. 3



v; and t = the time in seconds. Then c : 1 :: v : $\frac{v}{c} = t^n$, per question. $\therefore t = (\frac{v}{c})^{\frac{1}{n}}$. Again 1 : s :: t : st. $\therefore$ AB = $s\,(\frac{v}{c})^{\frac{1}{n}}$. But $BC^2 = AB^2 + v^2$; and BC : AB :: PC : PM $= x = b\,s\,(\frac{v}{c})^{\frac{1}{n}} \div \{s^2(\frac{v}{c})^{\frac{2}{n}} + v^2\}^{\frac{1}{2}}$; which reduced by putting $p = \frac{n}{2n-2}$ and $v = \left(\frac{s^2}{c^{\frac{2}{n}}}\right)^p \cdot \left(\frac{b^2 - x^2}{x^2}\right)^p$; becomes $y = v - (b^2 - x^2)^{\frac{1}{2}}$; the equation of the curve.

If $n = 1$, then v vanishes, and x is constant, being $= b\,s \div (b^2 + c^2)^{\frac{1}{2}}$; in which case the *locus* is a right line parallel to AC. If n be greater than unity, p is affirmative, and x^2 is in the denominator of v or y; consequently, when $x = o$, $y = \infty$, and AC is an asymptote to the curve. If n be a proper fraction, or p negative, the numerator of p becomes the denominator; and when $x = b =$ AV, $y = \infty$, consequently a line drawn parallel to AC through V, will in that case be an asymptote. When n is greater than unity, if $x = b$, then $y = o$, or the curve meets the line AB in the point V. When n is less than unity, if $x = o$, $y = -b$, or the curve meets the line CA produced to R till AR $= b$;—and in all cases the curve will cross the line AB, or it will somewhere be $v =$ MC $= (b^2 - x^2)^{\frac{1}{2}}$:—for, firstly, if p be negative, then when $x = o$, the equation gives $x = b$, but as x increases the first side of the equation increases, and the last decreases, whence

they must somewhere become equal. Secondly, when p is affirmative and $b^2 - x^2$ in the numerator * * * * * * from the nature of equations, there will always be an odd number of affirmative roots, and consequently at least one of them real.

The fluxion of the area $= -y\,dx = -d\left(\frac{b^2-x^2}{x^2}\right)^p dx + (b^2 - x^2)^{\frac{1}{2}}\,dx$; where if $p = 1$ or $-\frac{1}{2}$; $n = 2$ or $\frac{1}{2}$, the integral of the first member is had in finite terms, but in other cases it will require a series; and the integral of the last term = the segment ANTR of a circle whose radius $= b$ and ordinate NT $= (b^2 - x^2)^{\frac{1}{2}}$. Thus, if $n = 2$, as in Fig. 3, the corrected integral $= d\,b\left(\frac{b}{x} - 2\right) + d\,x$ — segment TVN; where $d = \left(s^2 \div \frac{2c}{n}\right)^p$. It is also readily had in other cases where $p =$ a whole number, or half of one. It may also be proper to observe, that c is not actually the space gone over by C the first second with a variable velocity, but the space which would be described in one second with the initial volocity of it continued uniform." During this year, Mr. Whiting commenced the publication of his *Scientific Receptacle*, and Mr. Dalton contributed the following question, and its solution, to the second and third numbers of that work. Its nature conveys the impression that he was now deeply engaged in those philosophical pursuits which he relinquished only with his life.

Question 39. *By Mr. John Dalton.* "There is a cylindrical glass vessel, with an upright tube, open at both ends, cemented into it. At the bottom of the vessel is a quantity of water, into which one end of the tube is immersed, and the upper part of the vessel confines a quantity of air. The diameter of the cylinder is 2 inches, of the tube $\frac{3}{10}$ of an inch, and of the bore $\frac{2}{10}$ of an inch. Now it is observed that when the air is of a certain temperature, and the barometer stands at 30·5 inches, the water in the tube is raised just 6 inches above that in the vessel, and this last is then 4 inches from

the top of the vessel. It is required to find how much higher the water will rise in the tube when the barometer falls to 28·5; the temperature being the same." Answer, 13·5 inches nearly.*

His contributions to the *Ladies' Diary* for 1792 are not so extensive as in former years. He furnished solutions to all the philosophical queries—three of which obtained insertion; and also to seven questions in the mathematical department of the Diary and its *Supplement.* Most of these are of an easy character, and could have added but little to his already well-established reputation. The editor, however, remarks in the *Supplement,* "that the ingenious answer to the prize question in the Diary by Mr. John Dalton was inserted in the copy but was obliged to be omitted at the press for want of room." In answer to the *first* query he asserts that "the pleasure arising from *conferring* an obligation, especially if it be effected without much inconvenience, is pure, and must be a grateful sensation to a generous mind;—but that arising from *receiving* an obligation is often mixed with the unpleasing reflection of inability to remunerate the benefactor;"—hence he concludes that the pleasure arising from the former must be greater than that arising from the latter. The *second* query conveys his sentiments relative to *second* marriages. He is of opinion that persons "of sensibility and virtue" are capable of feeling "an *equal* passion for *another* object," and "consequently the query may be answered in the affirmative." In his *third* answer he remarks that "probably spirits dissolve sugar solely by reason of the water they contain, and this being only a part of their composition, renders the solution more slow than when the menstruum is pure water."

* Mr. Dalton's object in proposing this question appears to have been the graduation of a *water* barometer. A well-constructed instrument of this description would obviously exhibit a *large* rise in the tube for a *small* variation of density in the atmosphere, but capillary attraction and the length of the apparatus required would materially interfere with its practical utility.

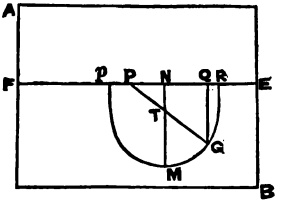
The second page of the *Gentleman's Diary* for 1792 contains Mr. Dalton's account of his observations on the eclipse of the sun, which happened on the 3rd of April in the preceding year. He gives the latitude of Kendal as "54° 20′ N.; longitude, 2° 50′ W.; the beginning of the eclipse 0h. 9′ p.m.; greatest obscuration, 1h. 34′; end of the eclipse, 2h. 53′; the duration, 2h. 44′;" and he is of opinion that "the errors in point of time will not exceed half a minute. The true noon was determined by a meridian line previously made; also by two equal altitudes of the sun the same day, both agreeing to half a minute. The sun's altitude was found at the end of the eclipse also, and the time of that was found by calculation to agree with the clock very nearly." From these observations Mr. Dalton was led to conclude that the tables then in use did not give the moon's latitude exactly; but the editor remarks, that "of this it is hard to judge, from observations made by those who are not in the constant practice of so doing." In the mathematical department he proposes one new question, and answers four in the previous list. Two of these solutions are inserted at length; and, at the close of that to the prize question, the editor expresses himself "much obliged to Mr. Dalton," and others, "for favouring him with the result of their labours upon this difficult problem" in dynamics. His next solution to Question 642 belongs to the interesting subject of geometrical maxima and minima; but since the problem is not very difficult, and merely relates to the construction of a triangle from given data, we prefer the selection of his solution to Question 648, on account of its relation to the prize question in the succeeding number of this Diary.

Question 648. *By Mr. John Gough.* "If a given pendulum be suspended on a pin fixed in the centre of gravity of a given vessel, resting on a horizontal and perfectly smooth plane, how far will the pendulum, descending from a horizontal position, move the vessel during one whole vibration;

what is the *locus* described by the weight of the pendulum? The weights of the vessel and pendulum being given, and the distance of their centres of gravity."

Answered by Mr. John Dalton. "Let p and R be the centres of gravity of the vessel and pendulum when horizontal; W and w their weights; then from p towards R, take pN : NR :: w : W, and N will be the common centre of gravity of the vessel and pendulum.

Fig. 4



The force of the pendulum upon the centre P at any instant may be resolved into two others, the one perpendicular and the other parallel to the horizon; the first of which only tending to increase the friction of the vessel upon the plane, by hypothesis, has no effect, and the other communicates the horizontal velocity to the vessel. Moreover, as the action between the vessel and pendulum is reciprocal, their common centre of gravity cannot be made to deviate from the vertical line NM; consequently the distance of their respective centres P and G from that line will be always the same; the pendulum will coincide with NM after half one vibration, and the whole space described by the vessel during one vibration will be $= 2p$N. Now let pR = PG = NM = a; and then NR = $a\frac{W}{W+w}$ = TG = b; also QG = x, and NQ = y. Then PG = a : PQ = $(a^2-x^2)^{\frac{1}{2}}$ :: TG = b : NQ = y; a known property of the ellipse, which is consequently the *locus* required."

Question 663. *By Mr. John Dalton.* "Two indefinite right lines form a right angle at C:—from a given point A in one of them draw lines to meet the other in D, on which set off AM : CD :: 1 : n :—required the quadrature of the curve, which is the *locus* of the point M?"

Answer by Mr. Gough. "The curve is a line of the

fourth order, having four similar infinite legs, two on each side of AC, which the curves touch in A both above and below. If from A, AB be set off = AO; BV produced will be an asymptote, parallel to which there is another equally distant from A, and on the contrary side of it. The space contained under the four legs, and two asymptotes is equal to a circle whose radius = AO." *(Diary, 1793, p. 42.)*

The *Ladies' Diary* and *Supplement* for 1793 contain answers from Mr. Dalton to *four* of the queries and *one* of the principal mathematical questions. He also furnished a solution to the prize, but after obliging two of his other correspondents, the editor expresses himself as "particularly sorry that [his] limits will not permit [him] to insert the general investigations of [his] learned correspondents, Amicus (Mr. Wildbore) and Mr. John Dalton." In the *Supplement* he discusses the question whether "the outward arc of the enlightened part of the moon's apparent disc is at any time apparently less than a semicircle," which had been proposed as an "astronomical query, by a Lunarian." On this subject he remarks, that "the outward arc of the enlightened part of the moon is commonly said to be a semicircle, and for the most part is nearly so; yet, strictly speaking, it is generally greater, and sometimes less, than a semicircle. The moon's disc as seen from the earth, is not bounded by a great circle of the moon, but by a parallel or lesser circle, and the visible segment is less than a hemisphere. The circle separating the light and dark parts of the moon is likewise a parallel circle; the dark segment being less and the light one greater than the hemisphere. Now, when the dark segment of the moon is greater than the segment visible at the earth, which happens when the moon is in perigee, then two extremities of some diameter of the visible disc may be involved in the dark segment, and consequently the enlightened arc will at that time be less than a semicircle, but this can only take place about the change." The reason

"why a light body floating in a tea cup, or other vessel, when approaching the side, moves towards it with a rapidly accelerated motion," is next explained by him to exist in "the universal attraction of matter," since an effect similar to this is that by which a plummet is drawn from the perpendicular by the attraction of a hill. His own inquiry why "after having been exposed for some time to a very cold wind, a person feels himself much benumbed, but soon after, on coming under shelter, the cold is suddenly changed into as great an extreme of heat," is accounted for by himself from the fact that "the internal principle producing" the *constant* heat of the blood, "whatever it may be, *must* perpetually vary in its effect, so as to counterbalance the opposite influence of the external air on the body, be it greater or less." Such being the case, cold must excite this principle to greater activity, and hence the extreme heat experienced under the circumstances of the query. The *fourth* query, Mr. Dalton observes, "points out its own answer. Metals being the best conductors of heat will cool fastest, and consequently the heat so communicated to the *metal* scale by the thermometer will be dispersed faster than that communicated to the *ivory* one, which consequently delays the ascent a little;—in the same manner as a vessel would be longer in filling with water when there was an aperture in the bottom of one inch diameter, than when the aperture was only half an inch diameter."

In the mathematical department his solution to question 951 is the only one printed at length. It was proposed by Mr. George Sanderson, of London, and requires "to determine on which day of the year 1792, the time between noon and sunset will be the greatest possible at Petersburgh in lat. 59° 56′ north." Mr. Dalton's investigation affords an interesting specimen of the use of the equation of time, and on this account appears well worthy of being transcribed.

Question 951. *Answered by Mr. John Dalton.* "By the word noon, in this question, I suppose is meant 12 o'clock,

the clock being duly regulated. It is well known that at the summer solstice the clock is before the sun, and consequently the equation of time is then to be added to the time per clock, or mean time, to reduce it to apparent time. Hence the equation of time being on the increase, the afternoons are longer than the forenoons, and are increasing on that account. And as the days decrease very slowly after the solstice, by reason of the slow decrease of the declination, and the equation of time increasing fast, the length of the afternoons will continue to increase after the solstice, till the decrease of the lengths of the days balances the equation of time. Hence the calculation will be easy to any one furnished with a nautical ephemeris. For, as radius : tang. lat. $= 59° 56'$ :: tang. dec. : sin. of ascensional difference. * * * * From which it appears that the afternoon of the 23rd of June will be the longest of any in the year at that place."

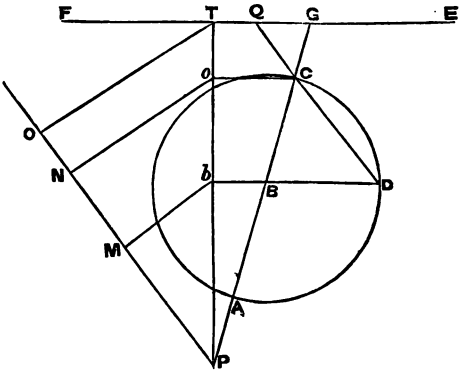
About this time still further honours awaited Mr. Dalton. He had already established his reputation as a mathematician and philosopher, and his efforts to obtain honourable distinction were now about to be crowned with success. In the early part of 1793 he had the satisfaction of having had awarded to him the "prize of six Diaries," for his solutions to the questions proposed in the *Gentleman's Diary*. Towards its close he was honoured by being selected, on the recommendation of Mr. Gough, as professor of mathematics in Manchester New College; and shortly after his removal to Manchester, he himself added permanency to his character as a natural philosopher by the publication of his still valuable *Essays on Meteorology*. His contributions to the *Gentleman's Diary* for this year are also tolerably extensive. They embrace one query, one new mathematical question, and ten solutions, including the prize, to those which had been proposed in the previous Diary. The solutions to question 665, and the prize, are inserted at length, the latter being honoured with the first place; while his own question (No. 663) is ele-

gantly investigated by Mr. Gough and Ferdinando (Mr. John Ryley). The prize is an extension of question 648, already noticed, by requiring "their velocities and the time of vibration" when the pendulum and vessel are "put in motion by the force of uniform gravity." Mr. Dalton first points out the intimate connexion between the two questions, and then investigates, *ab initio*, the required expressions in a very elegant manner. His solution to the remaining question furnishes an excellent specimen of geometrical composition, and is here selected as a proof that Mr. Dalton was not insensible to the attractive charms of the Greek geometry.

Question 665. *By Mr. Thomas White.* "From a given point P without a given circle, to draw a right line PAC cutting the circle in A and C, so that taking therein PB in a given ratio to BC; from B drawing BD to meet the circle in D, parallel to a right line EF given in position without the circle; and through D and C drawing a right line DQ meeting EF in Q; the two parts thereof DC and CQ may obtain a given ratio :—and to shew the limits of possibility."

Answered by Mr. John Dalton. "*Composition.* Let fall PT perpendicular to FE, from P draw any right line PO, on which take PM : MN in the given ratio of PB : BC; and MN : NO in the given ratio of DC : CQ;—join OT parallel to which draw N*o*, M*b* meeting PT in *o* and *b*; then draw *o*C and *b*D parallel to FE cutting the circle in

Fig. 5



C and D; lastly through C draw PG, DQ, and the thing is done."

Demonstration. For PM : MN :: P*b* : *bo* :: PB : BC; and since the triangles BCD, GCQ, are similar DC : CQ :: BC : CG :: *bo* : *o*T :: MN : NO; the given ratio.

Limitation. "If either of the parallels BD, *o*C, fall without the circle, the problem is impossible."

In the *Ladies' Diary* and *Supplement* for 1794, Mr. Dalton answers three of the queries and four of the mathematical questions, including the prize. The *first* query in the Diary was proposed by himself, and requires "the cause of the mist which is sometimes observable in a calm evening to hover over meadows and rivers." His explanation of the phenomenon, which agrees with that furnished by many other correspondents, is to the effect that the mist "is only observed when the air has suffered a sudden change of temperature from heat to cold. It is found from experience that warm air will hold more water in solution than cold air; therefore when the air is suddenly cooled, which sometimes happens in an evening, the water, being then much warmer than the air, evaporates pretty copiously at the surface, but is no sooner carried up a little into the cold air, than it is precipitated again in the form of mist, and occasions the phenomenon." The *Supplement* contains his theory of periodical winds, which is followed by an editorial notice of the publication of his essays on meteorology, and his own opinion on the effects of burning charcoal on steel. On the former subject he observes, that "the unequal capacities of land and water for receiving heat are undoubtedly the causes of these phenomena. Land receives more heat than water, or rather perhaps is heated to a greater degree. Independently, therefore, of the general or trade winds, the winds should blow *towards the centre* of the [West India] Islands in the day, and *from the centre* in the night; consequently, on the

eastern side of the islands, in the day, the winds occasioned by this cause *conspire* with the general east wind, and they *oppose* it on the western side, so that the velocity of the general wind will be increased in the one case, and diminished in the other; but in the night, the wind blowing from the internal parts towards the sea, will be felt in a greater or less degree, according to its strength, and as it conspires with, or opposes, the general eastern current."

In the mathematical portion of this Diary two of his solutions are inserted at length. One of them corrects an error in *Simpson's Fluxions* relating to the treatment of a fluxional equation, and the other determines the form and capacity of a certain vessel which empties itself uniformly through a given orifice. The list of new questions also contains one from Mr. Dalton, which is answered by himself and "Amicus" in the Diary for 1795:—its nature is remarkably indicative of the present tendency of his scientific pursuits, and is by no means unworthy of the author of the *Meteorological Essays* which had just been published when this question made its appearance. It is as follows:—

Question 978. *By Mr. John Dalton.* "There is a rain guage, or vessel with a circular aperture, set to receive the falling rain;—by some accident the guage has been turned aside a little, so that the plane of the aperture makes a given angle (5°) with the plane of the horizon, and the direction of the common section of the two planes is also given;—now, admitting that q = the quantity of water caught any day by the guage in such a position, and that the direction of the wind (S.W.) and the angle made by the falling rain with the horizon (30°) are both given;—it is required to determine, by a general theorem, the quantity of rain that would have been caught by the same guage if truly horizontal."

Answer. By considering the three planes as great circles of a sphere, forming by their intersections a spheric triangle

ABC, Mr. Dalton finds $\frac{q \cos. B}{\sin. A \sin. B \cos. C - \cos. A \cos. B} =$ "the required quantity of water; which is a general theorem in all cases."

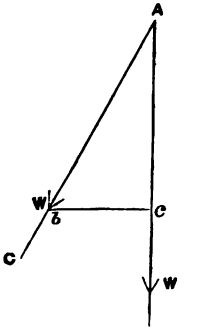
The second page of the *Gentleman's Diary* for 1794 announces the publication of his Essays, which are said to contain "several new theories, and what he conceives to be a complete discovery of the cause of the aurora borealis." In the mathematical department we find his solution to a question proposed by himself in the preceding Diary, but his "true and ingenious construction" to the geometrical prize question is reluctantly omitted for want of room." He also proposes question 699 in the list of new questions, which is answered by himself in the Diary for 1795. It relates to the motion of two bodies up two different inclined planes united at the vertex, but the solution is rendered less suitable for selection than the following, on account of its containing a reference to a similar question in a former Diary.

Question 681. *By Mr. John Dalton.* "Given two weights W and w, connected by a string going over a pulley at A, and an inclined plane AC moveable about an axis passing through A; now supposing the less weight w placed upon the plane at a given distance from A, whilst the greater W hangs freely from A; it is required to determine the velocity of the plane such that W may neither ascend nor descend:—also supposing the position of the plane at any instant given, to determine its initial velocity to make W ascend or descend by any given uniformly accelerating force within the limits of possibility."

Answered by Mr. John Dalton. "Let Ab = the given distance of w from A = r; Ac = any variable distance of the perpendicular distance bc from A = x; v = velocity of w;

and $2g = 32\frac{1}{6}$, the force of gravity. Then, per mechanics, the weight of w in direction $AC = \frac{w\,x}{r}$, or in opposition to the weight W:— consequently $W \mp \frac{w\,x}{r}$ = the weight acting in direction of the thread; the negative sign taking place when C is below A and the affirmative when above. Now it is obvious that if W do not descend, but continue at rest, the centrifugal motive force of w, divided by gravity, must be equal to this weight. Or $\frac{w\,v^2}{2\,g\,v} = W \mp \frac{w\,x}{r}$; whence $v = \left\{\frac{2\,g}{w}\,(Wr \mp w\,x)\right\}^{\frac{1}{2}}$, for the required velocity of w, or of the point b of the plane when the weight W continues at rest.

Fig. 6



When the plane is vertical below A, $x = r$, and $v = \left\{\frac{2\,g\,r}{w}\,(W - w)\right\}^{\frac{1}{2}}$, being then a minimum; if $x = c$, or the plane horizontal $v = \left(\frac{2\,g\,r\,W}{w}\right)^{\frac{1}{2}}$; if $x = r$, and the plane be above A, $v = \left\{\frac{2\,r\,g}{w}(W + w)\right\}^{\frac{1}{2}}$; being then a maximum:— lastly, if $W = w$, and the plane vertical below A, $v = o$, or the weights being equal, balance each other. If w be made to ascend with a force which is to gravity as $n : 1$; then we shall have $\frac{w\,v^2}{2\,g\,r} = W \mp \frac{w\,x}{r} + n\,W$, and consequently $v = \left\{\frac{2g}{w}(1 + n)\;W\,r \mp w\,x\right\}^{\frac{1}{2}}$; and when W is made to descend with a like force, n must be negative; but not so great as to make the quantity under the vinculum negative."

We have now arrived at the period when Mr. Dalton discontinued his correspondence to the mathematical periodicals. He had recently removed to Manchester, and the conscientious discharge of his duties, as professor of mathematics and natural philosophy, left him but few opportunities of indulging his taste for pure mathematics. The circum-

stances, however, which put an end to his mathematical correspondence impelled him to make greater exertions in the more interesting branches of experimental physics. He now possessed greater facilities for conducting his researches; and by bringing his well-trained mathematical genius to bear upon the results of his manipulations, he succeeded in penetrating the secrets of nature, and in a few years changed the whole aspect of chemical philosophy. Mr. Dalton was elected a member of this society in 1794, and read his first essay on a peculiarity of his own "Vision of Colours," in October of the same year. This paper was printed in the fifth volume of the first series of the Memoirs, and constitutes the earliest record of what is now technically termed "Daltonism," or "colour blindness," by the medical profession. In a subsequent volume he discusses with much acuteness the difficult problem of the diffusion of gases; and, by means of well-conducted experiments, succeeds in developing a series of fundamental principles respecting their specific gravities, which have not only been found of the highest importance to practical chemists, but have formed the basis of all subsequent investigations. His contributions to the various scientific journals are, on the whole, tolerably extensive, and many of them are of a very valuable character; but all of these must yield in importance to the "*New System of Chemical Philosophy*," which contains his grand discovery of the atomic theory. He had turned his attention to this theory as early as 1803, and was enabled to convince Dr. Thomson of its truth in 1804:—by 1807 he had satisfied both Wollaston and Davy that definite proportions constitute of necessity the true composition of matter, and this opinion had already become the prevailing doctrine of the continental philosophers. "It was Newton," says a recent writer, "who first put the conception of atoms into clear hypothetical connexion with the phenomena of chemistry; but it was Dalton that imparted enlargement, vitality, and fertility to the pertinent and memorable thought of the astronomer-royal of the

world. That mathematician described a *principle of proportion* lurking among the incondite mass of recorded chemical analyses * * * * which led him right to the revival of the Newtonian application of the idea of Democritus. * * * * Wollaston and Thomson were his earliest converts of established reputation. These ingenuous men, followed by Davy, Gay-Lussac, and Berzelius, and by the whole phalanx of the chemists of the present century, quickly carried the fact of chemical proportionals towards its consummation through a million of new and interesting particulars, and not a few important general deductions:—and *now* the theory stands embodied in the entire fabric of this most practical science." Previously to this discovery the practical philosopher had to grope his way through the elements of nature, without the possibility of extricating himself from the masses of confusion by which he was surrounded;—but no sooner did the light of Dalton's genius dawn upon the chemical horizon than chaos disappeared and order resumed her sway. Henceforth the path of the scientific explorer is directed by the pure rays of this pole star of nature—the atomic theory has deservedly immortalized the name of its expounder—and Dalton's application of mathematics to chemical philosophy will ever rank as one of the most brilliant discoveries of modern times.

II.—*On the Origin of Ironstones, and more particularly the newly discovered Red Stone at Ipstones, near Cheadle, Staffordshire; with some Account of the Ironstones of South Lancashire.*

By E. W. Binney, F.G.S.

[*Read November 15th*, 1853.]

The almost universal distribution of iron throughout the world is well known. This valuable metal, in addition to its wide range over the surface of the earth, occurs more or less in rocks of all ages, from the most ancient plutonic rocks up to the most recent peat bog deposits. Indeed, it is now sometimes seen in the very process of filling up the fissures in the sides of active volcanoes by sublimation from below. It is also found associated with a great variety of mineral substances and in most organic bodies.

The ores at present used in the manufacture of iron are, for the most part, the protoxide and sesquioxide. The former comprising the argillaceous and blackband ores, and the latter the hæmatites.

In ancient times, before coal came into general use for smelting purposes, iron was made in many districts of Great Britain and Ireland, by employing wood as fuel, in places where scarcely a trace of the manufacture is now left. Thus, in the weald of Sussex, many oolite and lias districts, as well as in limestone shale and devonian countries, furnaces were supplied with ores yielded by these respective formations. The occurrence of argillaceous iron ore, coal, and limestone

in the carboniferous strata, at convenient distances from each other, has latterly concentrated the iron manufacture on or near those deposits. This arises not so much from the richness of the carboniferous ores, for they are, comparatively speaking, poor in yield and not of the best quality, but from the necessity of economizing the expense in carriage of such large quantities of raw material. In no trade is the cost of transit so soon felt as in the iron manufacture. It has been most generally the custom to plant the furnaces on or near the supply of coal, and bring the ore and limestone to them.

At the present time, all the charcoal furnaces have disappeared, with the exception of some two or three near Ulverston, although in 1615 there were, according to Sturtevant, as quoted by Dudley in his curious old work, *Metallum Martis*, in Great Britain and Ireland, 800 furnaces, forges, or iron works making iron with charcoal.* Of these Dudley estimates that 300 of them, at 15 tons per week, would produce 180,000 tons per annum. The district of South Staffordshire, owing to its containing the ten yard coal, has long been the favourite seat of the iron manufacture. From the time of Dudley until now, the best of its argillaceous iron ores have been so extensively worked that they have become nearly exhausted, and others of a more inferior quality have had to be substituted. As the coal districts of South Staffordshire had superseded the old charcoal furnaces, they in their place appeared likely to give place to the blackband iron ore districts of Scotland and South Wales, although they were situate on the spot where a great amount of iron is used in the manufactures of the neighbourhood. But it is surprising how the eyes of men are sharpened by competition in searching for food to supply their devouring furnaces. Within the last year or two, the ironmasters of Durham and Northumberland were driven to the oolitic and lias ores of Yorkshire,

* On the Iron-making Resources of the United Kingdom, by S. H. Blackwell, Esq., F.G.S., p. 148.

which had been long noticed by geologists, whilst those of South Staffordshire had their attention directed to the oolitic deposits near Northampton. True it is that the ironmasters of South Staffordshire had for some years received a considerable amount of calcined blackband, from the rich deposit of that valuable mineral in the north of the county, found in the upper part of the Pottery coal field; but this had begun to be used in a great measure by the furnaces on the spot, and its extent is supposed not to be very great, unless it can be followed under the new red sandstone, which, I believe, has not yet been done; on this account the ironmasters of South Staffordshire have turned their attention to the ironstones of the oolite near Northampton and Blisworth. These are not of the richest class, and are much improved by the admixture of other ores, such as hæmatite.

Shortly after public attention had been directed to the deposits in the oolite of the midland counties nearest South Staffordshire, a gentleman of the name of Bishop discovered a bed of hæmatite in the lower coal measures at Ipstones, a few miles south of Leek; although I am informed that no one had in modern times worked this bed, from old workings and other circumstances there is little doubt that it was known in ancient times. Mr. Farey, in his Geology of Derbyshire and the Adjoining Counties, at p. 402 of Vol. I. of his work, in giving a list of the places where red and yellow ochres are found, states that they are to be met with in the coal measures near Dilhorn, in the same county (Staffordshire), and called raddle. However, he says, that none of these ores had been worked for iron making. Even so late as the year 1852, Mr. Blackwell, the eminent South Staffordshire ironmaster previously quoted, when he read his excellent paper at the Society of Arts, appeared not to be aware of the existence of this deposit, although he had been at the trouble of collecting some hundreds of specimens of the iron ores of the United Kingdom for the Great Exhibition.

The locality where I have chiefly examined the *red stone*,* as it is provincially termed, is at Booth's Wood, a little to the north of the village of Ipstones. The mine belongs to Mr. Bishop, the gentleman previously mentioned, and is very conveniently situated just above the canal. A level being driven into the hill side, the stone is brought out of the mine and loaded into the boats beneath by a shoot. The red stone here is from 18 to 20 inches in thickness, and the bed dips to the south-east at an angle of 4°. It is not uniform in quality, the richest portion being about 10 inches in the middle, and the top and bottom being of an inferior description. It is divided by regular joints, which render it easy of working, in bays of 8 or 10 yards in length. The price of the stone, put on board boats in the canal, I was informed was 12s. 6d. per ton. The floor of the stone is a poor kind of ironstone, containing some lime; and the roof is a brown coloured shale with a shell in it resembling the *Unio acutus*. In the stone itself I did not detect either iron pyrites or the remains of fossil shells or fishes; so it must be considered very free from sulphurets and phosphates, so detrimental to the manufacture of good iron.

The following section, in the descending order, will shew the nature of the strata both above and below the ironstone:

	yd.	ft.	in.
Black shale, containing marine shells, consisting of *Avicula papyracea, goniatites,* and *posidonia*	1	4	0
Coal (sulphury)	0	2	0
Brown fire clay	1	1	0
Fine grained light sandstone (Woodhead Hill Rock)...	8	0	0
Shale	10	0	0
Black shale	14	0	0
Small coal	0	0	8
Shale	5	0	0
Ironstone.....	0	1	6
Floor	0	2	0
Rough rock.....	30	0	0

* This term *red stone* must not be confounded with the valuable blackband of the upper part of the Pottery coal field, there also called red stone.

The strata above described belong to the lower coal field; and the 2 feet coal I consider to be identical in position with the New Mills coal, so extensively worked in the west of Derbyshire; whilst the rough rock is the same stone as that at Werneth Low.* The small coal of 8 inches I did not see myself, but was only told of its existence by a collier.

The coal above and the coarse rock below appear to be good guides in searching for the ironstone, which has been proved to extend to a considerable distance, although of variable thickness, and generally under that found at Mr. Bishop's works, previously described.

The rough rock, as well as being of the same age as that of Werneth Low, appears to me to be in the same position as those of Bagnall Church, Bolledge, and Wetley Moor.

The composition of the ironstone taken from the middle of Mr. Bishop's seam, according to the analysis of Dr. R. Angus Smith, F.C.S., our excellent secretary, to whom I am indebted for the trouble he has taken in making the same, is as follows:

Peroxide of iron	68.610
Silica	5.490
Carbonate of lime	18.170
Carbonate of magnesia	3.723
Manganese, alumina, and moisture	4.007
	100.000

The stone is of a brownish red colour, and has a slaty fracture parallel to its lines of deposition. Its cross fracture is rough and uneven. When smoothed, the face of the stone presents a finely laminated structure, the red parts being divided by belts and patches of a blackish colour. Its surface, parallel to the planes of deposition, frequently presents a blackish appearance, much resembling the protoxide of manganese. The 10 inches in the middle portion of the

* See section of the Lower Coal Field, Vol. X. (New Series) of the Society's Memoirs, p. 187.

bed is the richest, and it is from that part that the specimen analyzed by Dr. Smith was taken.

There is a well marked line of division between the top of the bed and its roof, but not so broad a line of demarcation between the bottom of the bed and its floor. Every part is more or less laminated, but less so in the middle than other portions.

On the whole, the chemical composition of the ore resembles that of some of the Northamptonshire ironstones from the oolite, especially in the great amount of the carbonates of lime and magnesia that it contains.

On the Deposits of Ironstone in Lancashire.

There is little doubt but that beds of ironstone, capable of being profitably wrought, exist in many districts besides that at Ipstones, mentioned in this communication and so lately discovered, and which have not hitherto been noticed, even near to some of our coal fields.

Looking nearer home than Ipstones, it has always been customary to assume that the coal field of Lancashire is destitute of beds of ironstone worth working. Although in ancient times doubtless considerable quantities of iron were manufactured from its argillaceous ores, especially those in the lower and middle coal fields* near Burnley, and which occupy the same position as the beds at Low Moor, from which that justly celebrated iron is made, still in modern times there have only been in operation the furnaces of Messrs. Swire and Co., at Dukinfield, in Cheshire, situate just on the verge of Lancashire. These were supplied with argillaceous ores procured from the middle coal field, and were not long in operation, having been soon discontinued. Whether this arose from the poor quality of the ore, or the unfavourable position of the

* For explanation of these divisions, see Paper, by the Author, On the Origin of Coal, printed in Vol. VIII. (Second Series) of the Society's Memoirs, p. 160, also Vol. X., p. 184.

measures which there dip at an angle of 30°, and thus render the minerals expensive to work, I cannot state; but it is most likely owing to the latter cause, which would tell seriously both on the price of the coal and ironstone.

In the lower division of the coal field there are numerous beds of argillaceous ore of such thickness as would be worked in many iron making districts.

In the middle coal field are many argillaceous and blackband ores fully as rich as those wrought in other places, and so situated that they could be calcined together with great advantage. Amongst the former are those of Clifton and St. Helens, and doubtless many other places in the same position; and amongst the latter the black stone above the cannel mine at Wigan, and several impure cannels and blackbands in that neighbourhood and about Dixon Fold. Below the 4 feet coal at Pendleton a carbonaceous blackband was found in sinking Mr. Fitzgerald's new pit, about 4 feet in thickness.

An analysis of this ore was made by Mr. John Leigh, F.C.S. 200 grains of the bed, taken as a fair average, gave—

Water	4.0
Bituminous matter and carbon	98.0
Silica	29.3
Silicates of iron, alumina, and lime	3.2
Alumina	4.5
Carbonate of lime	3.4
Peroxide of iron	57.0
	199.4

This gives 49 per cent. of combustible matter, and 28.5 of peroxide of iron, equivalent to 19.95 per cent. of metallic iron, certainly not a rich ore, but if mixed with the argillaceous stones of Clifton, and calcined together, capable of yielding a fair description of *mine*. In Lancashire, many beds of cannel run into blackband, in a similar manner to what often takes place in Scotland.

However, it is in the upper coal field that the most valu-

able ores occur. Above the four feet mine at Patricroft, and extending under Chat Moss, is a bed of the carbonate of protoxide of iron, about 2 feet 6 inches in thickness. This was found in sinking the shafts of Messrs. Lancaster and Co., at Patricroft, not far from the Liverpool and Manchester Railway. On analysis, the ore yielded about 72 per cent. of carbonate of iron, and the gentleman, a medical man, who analyzed it, told me that it was pure enough to be used for medicinal purposes.

Above the three-quarters mine at Bradford, and over the main limestone at Ardwick, are beds of blackband of 12 and 6 inches respectively in thickness, the representatives, beyond all doubt, of the red stone of the Pottery coal field, as their geological position, and the fossils they contain, are exactly the same.

Some of the above beds of ironstone only want thoroughly investigating to make them worthy of attention. Coal is, no doubt, much in demand for manufacturing purposes throughout the district, but for the last five years the average price has not been greater, if so much, as that paid by the iron-masters in South Staffordshire. Limestone is not very favorably placed, for both the Derbyshire, North Lancashire, and Clitheroe deposits are at considerable distances. The two last, however, are now accessible by rail.

The thick bed of carbonate at Patricroft before mentioned is free from the remains of fossil shells and fish, which will cause it to be in a great measure destitute of the compounds of phosphorus and sulphur, so detrimental to many of the argillaceous and blackband ores found in the carboniferous strata, and which are known to make so much cold short iron.

On the Origin of Ironstones.

All iron ores appear to have had their origin from volcanoes, however much they have since been mingled with the super-

ficial crust of the globe and the waters upon it. The case of the bed of iron before alluded to was mentioned in a recent publication in the following words, "The formation of lodes by sublimation may sometimes be observed at the present day in volcanic mountains. Thus, for instance, during an eruption of Vesuvius, in 1817, a fissure of more than 3 feet in diameter was filled within the space of ten days with specular iron ore deposited from the vapour of chloride of iron evolved."* Numerous lodes of specular iron ore, in different rocks of various epochs, clearly shew that these phenomena took place in many ages of the earth's history just as it did in the case first alluded to, the lodes resembling each other as much as possible. But the chloride of iron from volcanoes in ancient times, when there was most probably much less dry land than at present on the earth's surface, would more frequently flow into the waters of the sea than remain in the fissures of rocks. Subaqueous volcanoes, as the stratified beds of trap and volcanic ashes prove, were then of frequent occurrence. Now the chloride of iron might be ejected in at least three different ways: first, it might be ejected dry into the atmosphere, in which case chlorine and peroxide of iron would result; next, it might be ejected with vapour of water, in which case muriatic acid and peroxide of iron would be formed; and thirdly, it might be ejected into water, having lime either in solution or as a deposit. In this last case the lime would take the chlorine and throw down the peroxide of iron, leaving chloride of calcium in solution. In this liquid, if it were at all strong, no living beings could flourish. These eruptions of chloride of iron, at certain periods of the earth's history, would give us some clue to find out the cause why the red coloured deposits are so scantily supplied with organic remains. Both in the old red sandstone and the new red sandstone groups, organic remains, it is well known, are very sparingly found.

* Edinburgh New Philosophical Journal for October, 1853, No. 110, p. 348.

At the close of the silurian, carboniferous, and permian periods in England, great disturbances appear to have taken place in the earth's crust, and much sesquioxide of iron was mingled with the waters of the globe; but, at intervals, during the formation of the vast deposits accumulating during those three epochs, especially during the carboniferous, volcanic agency was doubtless more or less active, and thus supplies of iron would be sent into the sea from time to time.

After examining the beds of hæmatite found in the carboniferous strata in regular beds, as in the vicinity of Whitehaven, and those at Ipstones, forming the subject of the present communication, no one scarcely can doubt but that they had their origin in volcanic vents, and flowed into the waters of the sea, where they were deposited with the argillaceous and siliceous impurities found associated with them, layer by layer, like any other substances thrown down from suspension. This is evident from the beautifully laminated structure of the Ipstone bed.

The vast deposits of hæmatite found in the north of Lancashire, in the hundred of Furness, occur in great clefts of the carboniferous limestone.* These, no doubt, from their great purity, being but little mixed with foreign matters, had their origin from volcanic sources, on or near the spot where they are now found. Some of them probably may have come up through the bottom of the clefts in which they occur, and others from a short distance, and flowed with water into their present positions.

The argillaceous iron ores of the coal measures, now so generally used, have a composition, according to Dr. Colquhoun,† of—

* See Paper, by the Author, on the Geology of Low Furness, printed in Vol. VIII. (New Series) of the Society's Memoirs, p. 422.

† See Paper on the Iron Resources of the United Kingdom, by S. H. Blackwell, Esq., F.G.S., p. 151; read before the Society of Arts in April, 1852.

Carbonic acid	30.76
Protoxide of iron	38.80
,, manganese	0.07
Lime	5.30
Magnesia	6.70
Silica	10.87
Alumina	6.20
Peroxide of iron	0.33
Coaly matter	1.87
Sulphur	0.16
Moisture	0.00
	101.00

In the same valuable paper is an analysis of the North Staffordshire blackband ore, from the upper part of the Pottery coal field, made by Mr. Herapath, of Bristol. It is as follows: *

Protoxide of iron	42.25
Bilsulphate of iron	3.53
Protoxide of manganese	7.48
Silica	2.20
Alumina	0.50
Lime	4.09
Magnesia	2.60
Bituminous matter, carbonic acid, and loss	37.35
	100.00

In both the above specimens, traces of phosphoric acid, arising from the remains of shells, and fish bones and scales, would no doubt be found.

The argillaceous, as well as the blackband ores, would be formed under very similar conditions, except that the latter were, doubtless, produced amidst a much greater amount of decomposing vegetable and animal matters, as the great excess of bituminous matter appears to shew.

In a communication read before this Society,† the state of

* Page 153 of Mr. Blackwell's Paper.

† On the Origin of Coal, by E. W. Binney, Vol. VIII. (New Series) p. 148 of the Society's Memoirs.

the earth's surface, during the formation of coal, was shewn to be a shallow sea, in which grew successive crops of rank and luxuriant vegetation. The waters of this sea were more or less charged with mud, according to the currents flowing in it. In such mud, sesquioxide of iron would necessarily be present, some of it arising from the degradation of pre-existing rocks, and some from volcanic sources, like that from Mount Vesuvius, previously alluded to. Now both nodules of argillaceous and beds of blackband ores are found in fine grained argillaceous strata, shewing gentle currents of water, as the size of the mineral particles composing them prove. The former are often aggregated around a piece of vegetable matter, or the remains of shells or fishes, which appear to have had some power of attracting the iron from the surrounding mud, and the latter are mixed with a mass of the remains of plants, shells, and fishes.

Now, how has the sesquioxide of iron been converted into the carbonate of protoxide? This is well shewn on a small scale at the bottom of our ponds and waters, full of the *nymphæa alba*, or common water lily. Into these places waters containing more or less per oxide of iron flow, but the roots of the plants and other decomposing vegetable matter soon rob the iron of a dose of its oxygen, and convert the sesquioxide of iron into the protoxide, as Dr. Lyon Playfair, C.B., F.R.S.,* in a case shewing the origin of a peat bog at Downholland, in Lancashire, alluded to by the author, admirably shews. He says, "A curious case is pointed out by Mr. Binney in Lancashire, where there is evidence of a bank having been thrown up by the sea at the margin of one of those forests antecedent to its destruction. The effect of a bank thrown up at the margin of a forest must be to stop the

* On the Gases evolved during the Formation of Coal. Memoirs of the Geological Survey of Great Britain and Ireland, and of the Museum of Economic Geology in London, Vol. I., p. 478.

natural drainage of a country, and throw it into the state of marsh or bog. The roots of trees require an abundant supply of oxygen, which is an essential constituent of the sap, and exists in larger proportion than in common air in the spiral vessels. The marshy state of the land formed a barrier to the ingress of air to the soil, and, consequently, to the roots. The leaves that fell, the broken branches which strewed the ground, were placed in favorable conditions to decay. They could not do so by the mere action of the air, which was, to a great extent, precluded, and they, therefore, acted upon the peroxides of iron in the soil, and robbed it of its oxygen, as we know organic matter regularly does. All the iron in the soil was now reduced to protoxide, and a complete barrier to the entrance of oxygen to the roots was effected, for as soon as any was absorbed by the soil, it must have been appropriated by this lower oxide, which, on the elevation to the peroxide, again yielded it to the dead organic matter."

As soon as ever the sesquioxide of iron, whether derived direct from volcanic sources, or from the decomposition of pre-existing rocks in which it had been deposited, mingled with the mud at the bottom of the carboniferous sea, in which grew countless sigillariæ roots, like the leaves of the water lily, ramifying in all directions, not only would such living vegetables assist to decompose the peroxide of iron, but the dead branches and decaying roots would render further assistance, not merely in this way, but by supplying carbonic acid to convert the protoxide into such a carbonate as is now found in our coal measures.

Many of the argillaceous iron ores occur in detached nodules, which have frequently portions of vegetable matter, shells, fishes, or some other piece of organic matter in the inside that appears to have extracted the iron from the surrounding matrix; some of them are hollow, and contain crystals of carbonate of lime, and the sulphurets of iron, lead,

and zinc. The blackbands generally contain many remains of shells and fishes, with a good deal of bisulphide of iron.

The position of the bed of hæmatite at Ipstones, is between the upper part of the rough rock and the Woodhead Hill stone, somewhere near about the position of the 9 inch seam of coal in the Author's section of the Lower Coal Field of Lancashire.* In other districts where this little seam is found (and it is more constant in its thickness over a great distance than most other coals), some large deposits of carbonate of iron are met with in the shales above it; so iron then appeared generally present in the waters of the carboniferous sea, and the cause of the deposit at Ipstones being preserved from being converted into a protoxide, most probably arose from there being a less quantity of vegetable matter in the waters thereabouts than had been generally the case during the deposition of the carboniferous strata. The position of Ipstones, near to the carboniferous limestone of Derbyshire, in the western part of which, not far from Newhaven House, in Hartington, a distance of about eight miles, a vein of red iron ore occurs,† may also point to a source from which it could have come, and thus shew that there was no necessity for it to have been conveyed a very great distance from its probable source to the locality where it is now found. There is at present no evidence to prove the exact date of the formation of the vein of hæmatite above alluded to; but it was most certainly after the deposition of the mountain limestone, and it may have been ejected from below during the time of the deposition of the Ipstones bed, and part of it conveyed in water to the latter place.

* See Section at p. 184. Vol. X., of the Society's Memoirs.

† Vol. I., p. 265 of Farey's General View of the Agriculture and Minerals of Derbyshire. Besides this instance, I may mention the occurrence of considerable quantities of oxide of iron found associated with the lead and copper deposits of Mixon and other places, not more than four miles from Ipstones.

The occurrence of the iron as a sesquioxide at Ipstones in the carboniferous strata at the time of their formation, when the waters in which they were suspended were then generally more or less full of decomposing organic matter, can only be accounted for by its having been thrown into such waters near to the spot where it is now found, and not having had far to travel; for had it been mingled with decaying vegetable or animal matter, it would doubtless have been converted into the usual carbonate of the protoxide, so common in the coal measures.

III.—*On the Representation and Enumeration of Polyedra.*

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[*Read December 13th*, 1853.]

1. The relation between the faces, summits, and edges of a polyedron is expressed in the theorem following:

Theo. I. "The number of faces and summits in any polyedron taken together, exceeds by two the number of its edges."

For, let P be any polyedron having an $(e—f)$-gonal face E, contiguous at its edges and angles to e other faces of P. With f of these faces E will have no common edge; but if E be removed by a section E′ meeting all those e faces, P will become P′, a polyedron having an e-gonal face E′, contiguous to e other faces of P′; P′ having the same number of faces with P, but having f more summits and f more edges than P. If the e faces about E′ be produced to meet any face F produced of P′, P′ is included in the prismoid solid P″, whose two opposite e-gonal faces E′ and F are connected by e quadrilateral faces. Let now P′ be carved out of P″ by sections along faces of P′.

The first frustum p cut off from P″ will have k of the divided, and l of the undivided and removed edges of P″.

If $l=o$, p is a pyramid on a k-gonal base K; and it is evident that P″ diminished has lost a summit, in the vertex of

p, and gained one face, 3 edges, and 3 summits, in K and its sides and angles. Thus the number 3 of new edges of P″, is equal to that of the added face and summits together.

If $l > 0$, p carries away, with l complete edges, $l+1$ summits of P″, provided that the section passes through no summit of P″; but if it passes through i of them, p carries away l entire edges and $l-i+1$ summits of the prismoid solid. In the former case, P″ after section has lost l edges and $l+1$ summits, and gained one face, k edges, and k summits: in the other case, it has lost l edges and $l-i+1$ summits, while it has gained k new summits on its k divided edges, and $k+i$ new edges in its new face of $k+i$ angles.

The edges added to P″ are $k+i-l$, and the faces and summits added are $k+1-(l-i+1)=k+i-l$. Of course, i is either 1 or 2, or else 0.

Thus the increase in the number of edges in P″ after the first section, is equal to the increase of faces and summits together; and in the same way it is proved that a like equality holds after the second or the n^{th} section.

Now the theorem is true of P″, before it is cut; for it has $3e$ edges, $e+2$ faces, and $2e$ summits. It is consequently true after any section, and thus true of P′, the result of the final one, and therefore of P, which differs from P′ only by the subtraction of f edges and f summits. Thus Theo. I. is proved of any polyedron P, and that geometrically, in a manner which may probably be new.

2. The question—how many n-edrons are there?—has been asked, but it is not likely soon to receive a definite answer. It is far from being a simple question, even when reduced to the narrower compass—how many n-edrons are there whose summits are all triedral? Let us attempt to consider this, or at least the first step of this, problem.

If we take such an n-edron P, having n faces, s triedral summits, and e edges, and count the edges that meet in all

the summits, we have, since every edge is thus twice enumerated,

$$2e=3s,$$

and since $e+2=n+s$, by Theo. I.,

$$\therefore\ e+6=3n,$$

and $s+4=2n$.

This gives us the following:

Theo. II. *In any polyedron whose summits are all triedral, twice the number of the edges is thrice that of the summits; the number of edges plus six is thrice that of the faces; and the number of summits plus four is twice that of the faces.*

From this follows the truth of what may be called its polar theorem;

In any polyedron whose faces are all triangular, twice the number of the edges is thrice that of the faces; the number of edges plus six is thrice that of the summits; and the number of faces plus four is twice that of the summits.

Cor. 1. *No polyedron having only triedral summits can have an odd number of them.*

No polyedron having only triangular faces can have an odd number of them.

Cor. 2. *The number of edges in a* p*-edron is never less than* $\frac{3}{7}$p.

The number of edges in a p*-edron is never less than* $\frac{3}{7}$ *of the number of its summits.*

For the p-edron has the fewest edges when the faces have the fewest sides, *i. e.*, when they are all triangles; and of all the polyedra which have q summits, that will have the fewest edges whose summits have the fewest edges, that is, whose summits are all triedral.

Definition. *An* s*-peak is a polyedron having* s *summits.* This being premised and permitted, the second part of Cor. 2 is better stated thus:

The number of edges in an s*-peak is never less than* $\frac{3}{7}$s.

Cor. 3. *The greatest number of edges in a* p*-edron cannot exceed* 3p—6.

The greatest number of edges is an s*-peak cannot exceed* 3s—6.

This follows from Cor. 2 and Theo. I.

Cor. 4. *The number of faces in an* s*-peak is never less than* $\frac{1}{2}$(s+4), *nor greater than* 2s—4.

The number of summits in a p*-edron is never less than* $\frac{1}{2}$(p+4), *nor more than* (2p—4).

This is deduced from Theo. I. and the two preceding corollaries.

3. Here we may add conveniently the two following theorems.

Theo. III. *No* p*-edral* q*-peak has a face of so many as either* p *or* q *angles:*

No p*-edral* q*-peak has a summit of so many as either* p *or* q *edges.*

First: No q-peak has a face of q angles, for all its q summits cannot be in one face.

Secondly: No p-edral q-peak has a face of p angles; for if it has, it has at least $2p$ edges terminating at those angles, viz., the p sides of the face, and p others through their intersections. The remaining $q—p$ summits of the solid, not in that face, are connected by not less than $q—p—1$ edges, which number, added to the other $2p$ edges, cannot exceed $q+p—2$, by Theo. I.: *i. e.*,

$$2p+q—p—1 \underset{\angle}{=} p+q—2,$$

which is absurd.

The second part of the theorem is the polar property to the first.

Theo. IV. *No* p*-edral* q*-peak has a face of more than* 2q—p—1 *angles:*

No p-*edral* q-*peak has a summit of more than* 2p—q—1 *angles.*

For, let a face of a p-edral q-peak have $2q-p+r$ sides or angles. The remaining $p-1$ faces cannot have less than 3 sides each, nor can the sum of all the sides of the faces of the solid exceed twice the number of the edges, because no edge can be counted in more or less than two faces: *i. e.*,

$$2q-p+r+3(p-1) \leqq 2(p+q-2), \text{ or}$$

$$2q+2p+r-3 \leqq 2p+2q-4,$$

which is absurd.

4. Let now P be any n-edron with only triedral summits. It cannot have a face of more than $n-1$ angles, by Theo. III. Let it have an $(n-1)$-gonal face A, which is bounded by the $n-1$ faces, *abc* . . . . . *klm*, in that order. The $n-1$ summits of P about A are, in order, represented by the $n-1$ triplets

$$A\mathit{ab},\ A\mathit{bc},\ A\mathit{cd} \ldots\ldots A\mathit{lm},\ A\mathit{ma};$$

and since all the $n-1$ edges *ab*, *bc*, *cd* . . . . *lm*, *ma*, which meet A, must be found each at some second summit of P, these $n-1$ duads will appear in the $n-3$ triplets which represent the remaining summits of P; the whole number of those summits being $2n-4$, by Theo. II. This is impossible, unless some triplet contains two or more of these $n-1$ duads: now no triplet can exhibit three of them, for it would then contain more than three letters; nor can any two non-consecutive duads, as *ab* and *cd*, form a triplet. Let then *abc* be one triplet, in which *ab* and *bc* are exhibited: there remain $n-3$ duads to be disposed of in $n-4$ triplets, which cannot be, unless some one of these contains two of the duads.

There must then of necessity be, among the $n-3$ triplets to be added to those containing A, two of the form, *abc*, *jkl*,

which contain each two consecutive duads of the above written n—1, in other words, *which contain each three consecutive letters* out of *abc . . . lm*.

Let these two triplets be actually *abc* and *jkl*. The edges A*b*, *ab*, and *bc*, are in the face *b*; and the two edges *ab* and *bc* which pass through the summits A*ab* and A*bc*, meet in the summit *abc*. That is, *b* is a triangular face; and in the same way it appears that *k* is a triangular face. We have thus proved that our n-edron P must have at least two triangular faces. If, now, the restriction that all the summits shall be triedral be removed, the base being still (n—1)-gonal, it would not be difficult to show algebraically that the same necessity remains for at least two triangular faces; but I shall here content myself with a geometrical proof of the theorem following, which is under no restriction.

5. Theo. V. *If a* p*-edron has a* (p—1)*-gonal face, two at least of its faces are triangular.*

If a q*-peak has a* (q—1)*-gonal summit, two at least of its summits are triedral.*

For, since every side of the (p—1)-gon is the intersection of two faces of the p-edron, there can be no face which does not contain a side of the (p—1)-gon. The summits of the solid not in the plane of the (p—1)-gon must therefore be connected by a broken or branching line, which encloses no space, and which will have at least two extremities H and H′. The summit H, having only one edge (part of the broken line), which passes through a second summit out of the plane of the (p—1)-gon, must have at least two edges which pass through angles m and n thereof: *i. e.*, H*mn* is a triangular face. In the same way it is demonstrated that H′*m*′*n*′ is a triangular face of the p-edron.

The second part of the theorem is the corresponding polar property.

6. Returning to consider our n-edron P, having a $(n-1)$-gonal base and only triedral summits, and having only two triangular faces, abc and jkl, we have determined of its $2n-4$ summits the following $n+1$,

Aab, Abc, Acd, Ade . . . . . Ajk Akl Alm, Ama, abc, jkl.

The edges of the n-edron are $3n-6$ (Theo. II.). Of these, $n-1$ are sides of the $(n-1)$-gonal base, $n-1$ others pass through the angles of the base, and $n-4$ never meet the base, but form the broken line which connects the vertices of the two triangular faces. If we pass along this line from the triangular face k to the similar face b, we shall traverse all those edges of the intervening faces, l, m, and a, which do not meet the base. These $n-4$ edges are λ in the face l, μ in m, and a in a, such that $\lambda+\mu+a=n-4$. If $\lambda=1$, l has but one edge that does not meet the base, and as the duad jl, in the triplet jkl, must appear a second time, that one edge is jl, which must meet the edge lm, passing through the base angle Alm. In this case jlm is one of the triplets of the system. But if $\lambda=2$, jlm is not a triplet.

7. To clear the matter, let $n=14$.

$$\lambda=2,\ \mu=5,\ a=n-4-2-5=3.$$

In the triplets to be formed, we have to dispose of the duads

$$cd,\ de,\ ef,\ fg,\ gh,\ hi,\ ij,\ lm,\ ma,\ ac,\ jl,$$

which have been only once employed, and the whole system of triplets must exhibit no duad oftener or seldomer than twice.

One edge of the broken line in l is jl; the second must be il, meeting it in ijl, for i is the face next to j remote from jkl; and the duads il and lm must occur a second time: this determines the triplets

$$lij \text{ and } lmi.$$

Next we have 5 edges of the broken line on the face m, of which one is mi, because that duad must appear again, and the others are in order mi, mh, mg, mf, me. It is necessary

also to use the duads *hi*, *gh*, *fg*, *ef*, *ma*; hence the triplets following are determined,

mhi, *mgh*, *mfg*, *mef*, *mae*.

There are now 3 edges of the broken line in the face *a*, of which *ae* is one; they will be in order *ae*, *ad*, *ac*, which must be combined with the duads *de*, *cd*; therefore

ade, *acd*,

are determined. We have thus assigned all the 24 triedral summits of the 14-edron on a 13-gonal base, which has *two* triangular faces *k* and *b*, between which lie *three* faces *l*, *m*, and *a*; the values of λ, μ, and α described above being 2, 5, and 3. These triplets are

A*ab* A*bc* A*cd* A*de* A*ef* A*fg* A*gh* A*hi*
abc *acd* *ade* *mef* *mfg* *mgh* *mhi*
A*ij* A*jk* A*kl* A*lm* A*ma*
lij *jkl* *lmi* *mae*.

Of these summits 13 are in the face A, 7 in *m*, 5 in *l*, 5 in *e*, 5 in *a*, 4 in *h*, 4 in *i*, 4 in *j*, 4 in *c*, 4 in *d*, 4 in *f*, 4 in *g*, 3 in *b*, and 3 in *k*. The faces of P are one 13-gon, one heptagon, three pentagons, seven quadrilaterals, and two triangles.

8. The number of triangular faces is seen by inspection of the triplets; for it is equal to that of the triplets made with three consecutive letters; the middle letter, in alphabetical order, always denoting a triangle. There can never be two triplets made with four consecutive letters, as *abc*, *bcd*; for *bc*, which occurs in the summits of the base A, cannot twice occur again. Therefore *b* and *c* cannot both be triangles, nor *a* and *b*, nor any consecutive pair of faces. Hence follows

Theo. VI. *A* p-*edron, having a* (p—1)-*gonal face, and all its summits triedral, has not more than* $\frac{1}{2}$(p—1) *triangular faces, when* p *is odd, nor more than* $\frac{1}{2}$(p—2), *when* p *is even.*

A q-*peak, having a* (q—1)-*gonal summit, and all its*

faces triangular, has not more than $\frac{1}{2}(q-1)$ *triedral summits, when* q *is odd, nor more than* $\frac{1}{2}(q-2)$, *when* q *is even.*

9. Let us now consider the n-edron P, which has an $(n-1)$-gonal base A, all its summits triedral, and more than two—suppose, for example, four—triangular faces.

It is necessary to fix, first, the position of the triangles. The first being numbered one, the other three will be the $(e+2)^{th}$, the $(e+e_1+3)^{th}$, and the $(e+e_1+e_2+4)^{th}$, of the n faces $abcd$ . . . . . so that e faces lie between the first and second, e_1 between the second and third, e_2 between the third and fourth, and $(n-e-e_1-e_2-5)$ between the fourth and first triangle; where

$$n-e-e_1-e_2-5 \gtrless 0, \text{ or}$$
$$e+e_1+e_2 \lessgtr n-5.$$

Taking, for example, $n=15$, we may examine the case of

$$e=1,\ e_1=2,\ e_2=6,\ n-e-e_1-e_2-5=1.$$

The triangles are then a, c, f, m, which determine the triplets

$$nab,\ bcd,\ efg,\ lmn,$$

in addition to the fourteen

$$Aab,\ Abc,\ \ldots\ldots\ Amn,\ Ana.$$

Of the $39(=3n-6)$ edges, there are 14 just written in duads of consecutive letters ab, bc, &c., of which eight are repeated in the four preceding triplets, viz., na, ab, bc, &c. There remain six more duads of consecutive letters to be employed, of which no two can form a triplet; for the middle letter of such a triplet would denote a fifth triangle. But there are eight triplets yet to be determined to complete the $26(=2n-4)$ of the system. There must therefore be two triplets constructed which contain no duad of consecutive letters. These denote what I shall call *ridge-summits.*

If $a\gamma\varepsilon$ be one of them, the edge $a\gamma$ is the intersection of two non-consecutive faces α and γ; and it is evident, that if we proceed along this edge in either direction, we shall find

our way by a line of edges to some point in the base A, which lies between a and γ, or between γ and a, as the case may be, looking along the series of the faces $abcd \ldots n$, of which two are a and γ; and this point is an angle in a triangular face, which lies between a and γ, or between γ and a.

And if between a and γ there be more than one triangle, we shall arrive by proceeding from $a\gamma\varepsilon$ along $a\gamma$ to one or more such summits as $a\gamma\varepsilon$, the unions of branches of the ridge line leading to such triangles, and this only along edges of faces between a and γ (a and γ being included among them): so that no face θ which does not lie between a and γ, can be one at such a summit. And if there be several triangular faces lying between γ and a, we shall, by proceeding along $a\gamma$ through the point $a\gamma\varepsilon$, arrive at one or more of such (summits or) triplets made with faces that lie between γ and a (these two being included): *i. e.*, no face β which lies betwen a and γ can form part of such a triplet.

10. Generally, if there be k triangular faces, there are to be added to the triplets denoting their vertices and the $n-1$ angles of the base

$$2n-4-n+1-k=n-3-k$$

triplets; of which there cannot be either more less than $n-1-2k$, which contain each a duad of consecutive letters, this being the number of such duads remaining to be repeated. There must be, therefore,

$$n-3-k-(n-1-2k)=k-2$$

triplets containing no duad of consecutive letters.

If $a\gamma\varepsilon$ and $\theta\lambda\phi$ be two of these, there must be at least one triangle lying between a and γ, and at least one between γ and a; and the same must be true of $\theta\lambda$, $\phi\theta$, &c.: nor can λ lie between a and γ, unless θ λ and ϕ all lie between them, a and γ being counted as so lying. Here a and θ might be one and the same.

11. Returning to our 15-edron P, whose triangular faces are *a*, *c*, *f*, and *m*, we may choose at pleasure two ridge-summits from the series

0 *b* 0 *d e* 0 *g h i j k l* 0 *n*,

(in which the zeros denote the triangles) under the restrictions just laid down. Let *bdj*, *knb* be the triplets. We have to complete the system

A*ab* A*bc* A*cd* A*de* A*ef* A*fg* A*gh* A*hi* A*ij* A*jk* A*kl* A*lm*
bcd *de* *efg* *gh* *hi* *ij* *jk* *kl*
A*mn* A*na* *b·d·j* *k·n·b*
lmn *nab* *dj* *jb* *kn* *bk* *eg* *ln*; where the points in *b·d·j* and *k·n·b*, shew duads of non-consecutive letters.

We dispose first of *dj* and *kn*, between either of which lies a single triangle. The edge *dj* leads from the point *bdj* to the triangle *f*, along *d* and *e* on one hand, and *jih* and *g* on the other. We must have either *de·j* or *d·ij* for a summit lying between *bdj* and *f*; for *dj* cannot lead *from* *bdj* to any others constructible: thus we must have one of the two systems

de·j, *ji·e*, *hi·e*, *gh·e*; *d·ij*, *d·hi*, *d·gh*, *de·g*;

either of which conducts along *eg* to *efg*, by triplets of the proper form, which repeat every duad that they introduce, and dispose of *de*, *ij*, *hi*, *gh*, and *ge*. The summits *de·j*, *ji·e*, &c., known by the single point, I call *wall summits*.

The edge *kn* leads along *n* to the triangle *m*, and the only triplet possible is *kl·n*, which disposes both of *kn* and *ln* as well as of *kl*.

The edge *jb* can enter no triplet but *b·jk*, for no duad containing *j* is disposable besides *jk*: this uses *bk*; and all our duads are now twice employed. We have then these two systems, each of 26 triplets;

A*ab* A*bc* A*cd* A*de* A*ef* A*fg* A*gh* A*hi* A*ij* A*jk*
nab *bcd* *j·de* *efg* *e·gh* *e·hi* *e·ij* *b·jk*
A*kl* A*lm* A*mn* A*na* *b·k·n*
n·kl *lmn* *b·d·j*;

Aab Abc Acd Ade Aef Afg Agh Ahi Aij Ajk
nab bcd g·de efg d·gh d·hi d·ij b·jk
Akl Alm Amn Ana b·k·n
n·kl lmn b·d·j.

The first has the fifteen faces, *Aab . . . lmn*, in order, of 14, 3, 7, 3, 5, 7, 3, 4, 4, 4, 6, 5, 4, 3. 6 angles, and may be represented by

A *a b c d e f g h i j k l m n*:
14 3 7 3 5 7 3 4 4 4 6 5 4 3 6

the second differs only from this in the faces *d*, *e*, *g*, and *j*, and is represented by

A *a b c d e f g h i j k l m n*.
14 3 7 3 8 4 3 5 4 4 3 5 4 3 6

There are then two 15-edrons which have only triedral summits, stand on a 14-gonal base, have four triangles, *a*, *c*, *f*, and *m*, between which intervene 1, 2, 6, and 1 faces, and have the same two *ridge-summits* *b·d·j* and *b·k·n*. And, of course, there are two 15-peaks which have twenty-six triangular faces, have one 14-edral summit, have four triedral summits *a*, *c*, *f*, and *m*, between which intervene, counting the edges in order round the 14-edral summit, 1, 2, 6, and 1 edges, and have the same two faces *b·d·j* and *b·k·n*, no two of whose angles, as *b* and *d* or *b* and *n*, are on a consecutive pair of the edges about the 14-edral summit.

These 15-peaks are accurately represented by the above systems of triplets, in which *abc . . . n* stand for summits, not faces, namely the summits which in order lie on the 14 edges of the 14-edral summit A.

12. The species of a n-edron on a $(n-1)$-gonal base, having k triangles, may be said to be determined, when the number and position of the k triangular faces are assigned, with the $k-2$ ridge-summits. Of this species there may be no varieties or many. The varieties depend on the manner

in which the broken or branching *ridge-line*, which connects the ridge-summits and vertices of the triangles, proceeds along the intervening faces. The species considered in the preceding article has two varieties. It may be worth while to work out another example.

Let there be again 15 faces, one 14-gonal face A, and only three triangles, *b*, *f*, and *m*; and let *d·j·n* be the ridge-summit. We have to complete the system

A*ab* A*bc* A*cd* A*de* A*ef* A*fg* A*gh* A*hi* A*ij* A*jk*
abc *cd* *de* *efg* *gh* *hi* *ij* *jk*
A*kl* A*lm* A*mn* A*na* *d·j·n*
kl *lmn* *na* *dj*, *jn*, *nd*, *ac*, *eg*, *ln*.

If we look at the series

a 0 *c d e* 0 *g h i j k l* 0 *n*,

we see that *dj* leads from the point *djn* to the triangle *f*, along the faces *jihg* on one hand and *de* on the other. We have the choice of the two triplets *de·j* and *d·ij* for the disposal of *dj*: take *de·j*. This make *ei·j* inevitable, for *ej* must be repeated; after which *e·hi*, *e·gh* are determined, and all our duads thus far are repeated. Taking *d·ij*, we must have of necessity *d·hi*, *d·gh*, and *de·g*, which closes our circle of duads. Thus we have either

de·j, *e·ij*, *e·hi*, *e·gh*; or else
d·ij, *d·hi*, *d·gh*, *de·g*;

either of which disposes of *de*, *eg*, *gh*, *hi*, *ij*, *jd*.

Next, we see that *jn* leads from *djn* to *m* only along *n*; and we can make no other triplets than

jk·n, *kl·n*.

The edge *nd* leads to *b* along *d* and *c*. We can write either *na·d* or *cd·n*; that is, we may have either

na·d, *a·cd*; or *cd·n*, *na·c*.

Hence the species of 15-edron—having triedral summits, a 14-gonal face, three triangular faces, between which inter-

vene in order 3, 6, and 2 faces, and a ridge-summit made by the faces which are separated from those triangles the first from the first by one face, the second from the second by three, the third from the third by no faces, counting in the order of those triangles—has four varieties, which are the following, each of 26 summits.

A*ab* A*bc* A*cd* A*de* A*ef* A*fg* A*gh* A*hi* A*ij*
abc *a·cd* *j·de* *efg* *e·gh* *e·hi* *e·ij*
A*jk* A*kl* A*lm* A*mn* A*na*
n·jk *n·kl* *lmn* *d·na* *d·j·n.*

A*ab* A*bc* A*cd* A*de* A*ef* A*fg* A*gh* A*hi* A*ij*
abc *n·cd* *j·de* *efg* *e·gh* *e·hi* *e·ij*
A*jk* A*kl* A*lm* A*mn* A*na*
n·jk *n·kl* *lmn* *c·na* *d·j·n.*

A*ab* A*bc* A*cd* A*de* A*ef* A*fg* A*gh* A*hi* A*ij*
abc *a·cd* *g·de* *efg* *d·gh* *d·hi* *d·ij*
A*jk* A*kl* A*lm* A*mn* A*na*
n·jk *n·kl* *lmn* *d·na* *d·j·n.*

A*ab* A*bc* A*cd* A*de* A*ef* A*fg* A*gh* A*hi* A*ij*
abc *n·cd* *g·de* *efg* *d·gh* *d·hi* *d·ij*
A*jk* A*kl* A*lm* A*mn* A*na*
n·jk *n·kl* *lmn* *c·na* *d·j·n.*

The faces are described thus:

A	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*	*n*
14	5	3	4	6	7	3	4	4	4	6	4	4	3	7
14	4	3	5	5	7	3	4	4	4	6	4	4	3	8
14	5	3	4	9	4	3	5	4	4	5	4	4	3	7
14	4	3	5	8	4	3	5	4	4	5	4	4	3	8.

To give an example of the maximum number of triangles, let $n=14$, $k=6$: let the triangles be *b*, *d*, *f*, *h*, *j*, *l*, and the ridge summits be *aeg*, *ace*, *akg*, and *gik*.

We have to complete the system

$$\begin{matrix} A_{ab}, & A_{bc}, & A_{cd}, & A_{de}, & A_{ef}, & A_{fg}, & A_{gh} & A_{hi} \\ & abc & & cde & & efg & & ghi \end{matrix}$$

$$\begin{matrix} A_{ij} & A_{jk} & A_{kl} & A_{lm} & A_{ma}, & gik, & akg, & aeg, & ace, \\ & ijk & & klm & ma, & mk, & ak; & & \end{matrix}$$

which can be effected but in one way, by the addition of *akm*.

When a $(2n+1)$-edron on a $2n$-gonal base has n triangles, the system consists of no triplets besides those denoting the summits of the base and of the triangles, and the ridge-summits.

13. It would perhaps not be a *very* difficult matter to discover an algebraic expression for the number of n-edrons which have a $(n-1)$-gonal face, with all their summits triedral.

All that is necessary, is, first, to find the number N of solutions of (vid. 9)

$$e+e_1+e_2+ \ldots . +e_{k-2} \angle n-k-1,$$

e, e_1, &c., being positive, and k not less than 2, nor greater than $\frac{1}{2}(n-1)$, and every different order of the numbers $e\,e_1\,e_2$, &c., counting as a solution; for every such permutation gives a different polyedron. This number N is known and readily found. Then it would be required to find the number R of ways in which $k-2$ ridge-summits could be selected, under the restrictions of article (10). The sum ΣNR, from $k=2$ to $k=$the greatest integer in $\frac{1}{2}(n-1)$, is the number of *species*. Each of these is then to be multiplied by the number of its varieties V, which arise in the manner of those above discussed in (7) and (12). The full number required is ΣNRV taken within the proper limits.

14. Leaving the pleasure of this discovery to the learned reader, I shall proceed to consider the construction of n-edra which have all their summits triedral and no face of more than $n-e-1$ angles.

It is evident that there must be, in such an n-edron P, e faces which do not meet the $(n-e-1)$-gonal base A: and it will be convenient to say that P has e *crown-faces*, or e *crowns*.

First, let $e=1$; and let $n=8$; the base or most-angled face is a hexagon, and the crown cannot have more angles than the base. Suppose it also hexagonal. We shall have of course a system of triplets symmetrical with regard to the base A and the crown C; viz.

$$\begin{array}{l} A\,ab\ A\,bc\ A\,cd\ A\,de\ A\,ef\ A\,fa \\ C\,ab\ C\,bc\ C\,cd\ C\,de\ C\,ef\ C\,fa, \text{ or} \\ \quad A\ C\ a\ b\ c\ d\ e\ f \\ \quad 6\ 6\ 4\ 4\ 4\ 4\ 4\ 4 \end{array} \qquad (1)$$

Next, let the crown be pentagonal. The system

$$\begin{array}{l} A\,ab\ A\,bc\ A\,cd\ A\,de\ A\,ef\ A\,fa, \\ C\,ab\ C\,bc\ C\,cd\ C\,de\ C\,e\,a, \qquad ef,\ fa,\ ea, \end{array}$$

must be completed; which can only be by the triplet efa, giving us

$$\begin{array}{l} A\ C\ a\ b\ c\ d\ e\ f. \\ 6\ 5\ 5\ 4\ 4\ 4\ 5\ 3 \end{array} \qquad (2)$$

It is to be observed that, while in the former system there are none but duads of consecutive letters, neglecting A and C, there is of necessity in the latter one duad ea in Cea of non-consecutive letters combined with C. Nor can there be more; for C must combine with exactly five letters, twice with each, so that two duads used with A, namely, those containing the sixth letter, must remain unemployed with C. But as there can only be $(2n-4=)$ 12 triplets, not more than one duad besides those two can remain to be repeated: if now C had two duads of non-consecutive letters, two used with A and two used with C would remain to be repeated; which is absurd.

15. When C is 4-lateral, it may combine with one duad of non-consecutive letters, or with more. If with one only, the system to complete by two additional triplets is

A*ab* A*bc* A*cd* A*de* A*ef* A*fa*
C*ab* C*bc* C*cd* *de* *ef* *fa* C*da* *da*:

which determines either *def* and *dfa* to be the required triplets, or else *efa* and *ead*, giving

either A C *a b c d e f*
6 4 5 4 4 6 3 4
or A C *a b c d e f.*
6 4 5 4 4 5 4 3 } (3)

Of these two, one is merely the reflected image of the other, the faces about the base being like and in like order.

If C has two non-consecutive duads, they may occur at adjoining or non-adjoining summits in C. This gives two systems:—

A*ab* A*bc* A*cd* A*de* A*ef* A*fa*
C*ab* C*bc* *cd* *de* *ef* *fa* C*ce* C*ea* *ce* *ea*,

which demands *cde* and *efa*; and

A*ab* A*bc* A*cd* A*de* A*ef* A*fa*
C*ab* *bc* *cd* C*de* *ef* *fa* C*bd* C*ea* *bd* *ea*,

which requires *bcd* and *efa*; and the faces stand thus,

A C *a b c d e f*, (4)
6 4 5 4 5 3 6 3

A C *a b c d e f.* (5)
6 4 5 5 3 5 5 3

C cannot be combined with three duads of non-consecutive letters, for in that case there would remain to be repeated those three besides five of those employed with A; but to complete the 12 there are only two triplets required, which cannot dispose of eight duads.

16. Next let C be triangular: it may be combined with one or more duads of non-consecutive letters. If with one only, the system is, requiring three triplets more,

A*ab* A*bc* A*cd* A*de* A*ef* A*fa*
C*ab* C*bc* *cd* *de* *ef* *fa* C*ca* *ca*.

This admits of cde, $a{\cdot}c{\cdot}e$, efa,
of def, $d{\cdot}fa$, $a{\cdot}dc$,
of $fa{\cdot}c$, $c{\cdot}ef$, cde,
or of efa, $a{\cdot}de$, $a{\cdot}cd$;

the faces stand thus,

$$\begin{array}{lll} \mathrm{A\ C}\ a\ b\ c\ d\ e\ f & & (6) \\ 6\ \ 3\ 6\ 4\ 6\ 3\ 5\ 3 & & \\ \mathrm{A\ C}\ a\ b\ c\ d\ e\ f & & (7) \\ 6\ \ 3\ 6\ 4\ 5\ 5\ 3\ 4 & & \\ \left.\begin{array}{l} \mathrm{A\ C}\ a\ b\ c\ d\ e\ f \\ 6\ \ 3\ 5\ 4\ 7\ 3\ 4\ 4 \end{array}\right\} & & (a) \\ \left.\begin{array}{l} \mathrm{A\ C}\ a\ b\ c\ d\ e\ f \\ 6\ \ 3\ 7\ 4\ 5\ 4\ 4\ 3 \end{array}\right\} & & \end{array}$$

The two latter are excluded, because one face is heptagonal: the octaedron standing on that base has no crown, and ought to be described among those that have a 7-gonal base.

Let now C be combined with two duads of non-consecutive letters.

Here it will be useful to demonstate the following theorem.

Theo. VII. *If* r *of the summits in the crown* C *of an* n*-edron on an* (n—2)*-gonal base, having only triedral summits, are bounded by pairs of faces which are not contiguous faces about the base, that* n*-edron will have at least* r *triangular faces about the base.*

For let C$\gamma\theta$ be such a summit of C, γ and θ not being contiguous faces about the base. The edge $\gamma\theta$ proceeding from C$\gamma\theta$ must be a portion of a broken or branching ridge-line which encloses no space, because there is no crown but C. It will have at least one extremity H. This summit H, having only one edge passing through a summit out of the base, will have two edges passing through angles m and n of the base; *i. e.*, Hmn is a triangular face lying between γ and θ.

17. We must, by virtue of this theorem, have two triangular faces about the base of our 8-edron. Let those triangles first be a and c, separated by one face b only.

The system to be completed by four more triplets is

$$A\alpha b \; A\beta c \; A\gamma d \; A\delta e \; A\varepsilon f \; A\zeta a$$
$$f\alpha b \quad b\beta c \quad c\gamma d \quad d\delta e \quad e\varepsilon f \quad f\zeta a.$$

C must have one duad of consecutive letters: either Cde, or Cef, must be written: which can only be followed by Cdb, Ceb, bef, or Ceb, Cfb, bde, respectively, as is easily verified. But either of these sets of four repeats b four times, which has thrice occurred before, thus introducing a heptagonal face, which is here inadmissible.

The faces here determined would be

$$\left.\begin{matrix} A\ C\ a\ b\ c\ d\ e\ f \\ 6\ 3\ 3\ 7\ 3\ 5\ 5\ 4 \\ A\ C\ a\ b\ c\ d\ e\ f, \\ 6\ 3\ 3\ 7\ 3\ 4\ 5\ 5 \end{matrix}\right\}(A)$$

which are two octaedra on a heptagonal base b, the one the reflected image of the other.

We take then a and d for our triangles, opposite faces about the hexagonal base. Looking now at

$$A\alpha b \; A\beta c \; A\gamma d \; A\delta e \; A\varepsilon f \; A\zeta a,$$
$$f\alpha b \quad b\beta c \quad c\gamma d \quad d\delta e \quad e\varepsilon f \quad f\zeta a,$$

we see that it is of no consequence whether we take Cbc or Cef for the triplet containing a duad of consecutive letters, because all is symmetrical about the opposite faces.

Taking the former, we must write either

$$Cbc \; Cbf \; Cfc \; fce, \text{ or } Cbc \; Cce \; Ceb \; bef,$$

which give the faces

$$\begin{matrix} A\ C\ a\ b\ c\ d\ e\ f, \\ 6\ 3\ 3\ 5\ 6\ 3\ 4\ 6 \end{matrix} \qquad \begin{matrix} A\ C\ a\ b\ c\ d\ e\ f, \\ 6\ 3\ 3\ 6\ 5\ 3\ 6\ 4 \end{matrix} \quad (B)$$

which are merely reflected images of each other. Further, if we take a for base in the figure (6) of the last article, and d for crown, we find that (6) is equally represented by

$$\begin{matrix} a\ d\ (C\ c\ e\ f\ A\ b), \\ 6\ 3 \quad 3\ 6\ 5\ 3\ 6\ 4 \end{matrix}$$

CcefAb being the faces which lie in order about a, as is evident from the triplets aCc, ace, aef, afA, aAb, abC: therefore (6) and (B) are the same octaedron.

Let C next appear with three duads of non-consecutive letters. We write the scheme with three triangles *b*, *d*, *f*,

$$\begin{array}{cccccc} Aab & Abc & Acd & Ade & Aef & Afa \\ abc & & cde & & efa & ac\ ce\ ea. \end{array}$$

We have three triplets to add containing C, which can be only C*ae* C*ce* C*ea*. These faces are

$$\begin{array}{c} A\ C\ a\ b\ c\ d\ e\ f. \\ 6\ 3\ 6\ 3\ 6\ 3\ 6\ 3 \end{array} \qquad (8)$$

There are thus found eight octaedra on a hexagonal base, having all their summits triedral.

18. We shall now examine the octaedra which have no face of more than five angles. There must then be two crowns.

Two crowns may in general be adnate by a common side, or connected by an intervening edge or broken ridge-line. If an intervening edge connects them, it is the side of a face at least hexagonal, if the summits are triedral; for that face must have two angles common with either crown besides two in the base. Our crowns, therefore, must be adnate at two summits; and the sum of their other summits cannot exceed five, because only one edge can pass to the pentagonal base from each of them.

Let the crowns be a pentagon C and a quadrilateral D. It is evident that between the two faces at the common summits of C and D there can intervene neither more nor less than one of the five faces about the base. Let *a* and *c* be the two. Then the triplets CD*a* CD*c* determine all the rest, for D must appear only twice more, and with every letter twice; thus—

$$\begin{array}{l} Aab\ Abc\ Acd\ Ade\ Aea\ CDa\ CDc \\ Dab\ Dbc\ Ccd\ Cde\ Cea; \end{array}$$

$$\begin{array}{c} A\ C\ D\ a\ b\ c\ d\ e. \\ 5\ 5\ 4\ 5\ 4\ 5\ 4\ 4 \end{array} \qquad (9)$$

19. When of two adnate crowns one is a triangle, there may intervene in general between the faces joining them at their common summits one or more faces, or none.

If the crowns of our octaedron are a pentagon C and a triangle D′, those faces at the common summits must be contiguous on the base, otherwise the summits would be angles of at least hexagons, containing each three angles on the two crowns, one in the face intervening between those non-contiguous faces, and two in the base. The common summits must therefore be CD′*a* CD′*b*.

We have to complete

A*ab* A*bc* A*cd* A*de* A*ea* CD′*a* CD′*b*
D′*ab* *bc* *cd* *de* *ea* C*a* C*b*.

As *a* and *b* cannot occur more than a fifth time, we must write C*ea* and C*bc*, whence of necessity C*ec* and *cde*.

This gives the faces

$$\begin{matrix} A & C & D' & a & b & c & d & e. \\ 5 & 5 & 3 & 5 & 5 & 5 & 3 & 5 \end{matrix} \qquad (10)$$

20. Two quadrilaterals, or a triangle and a quadrilateral, cannot be our two crowns, the base or most-angled face being pentagonal; for, as there must be seven summits out of the base, it will happen in either case that a face will contain three summits on the two crowns, two in the base, and one neither in the base nor the crowns. Two triangles cannot be adnate crowns, the summits being all triedral, because, of their common summits, only one can present to the base an angle less than two right angles; and that which is not less than two can be no angle in any face.

The base or most-angled face of an octaedron having only triedral summits cannot be less than pentagonal; for there must be 3×12 angles counted in all the faces, but $4\times8=32$ only.

I have thus found all the octaedra which have not a heptagonal face, and which have all their summits triedral. They may be collected briefly as follows:

(1) A C *a b c d e f*
6 6 4 4 4 4 4 4

(2) A C *a b c d e f*
6 5 5 4 4 4 5 3

(3) A C *a b c d e f*
6 4 5 4 4 6 3 4

(4) A C *a b c d e f*
6 4 5 4 5 3 6 3

(5) A C *a b c d e f*
6 4 5 5 3 5 5 3

(6) A C *a b c d e f*
6 3 6 4 6 3 5 3

(7) A C *a b c d e f*
6 3 6 4 5 5 3 4

(8) A C *a b c d e f*
6 3 6 3 6 3 6 3

(9) A C D *a b c d e*
5 5 4 5 4 5 4 4

(10) A C D *a b c d e*
5 5 3 5 5 5 3 5

The fourth and seventh of these have each two hexagons, two pentagons, two quadrilaterals, and two triangles; but they are different polyedra, their crowns being different when they are made to stand on hexagonal faces. Thus we see that a polyedron is not determined, when the angular rank of its faces and summits is given. The triplets which represent the summits of these octaedra will of course equally denote and describe the faces of those 12-edrons whose faces are all triangular, and which have no summit of more than six edges; if the letters *a*, *b*, *c*, &c. be taken for summits, not faces.

21. The remainder of the octaedra having triedral summits, namely, those on a 7-gonal base, I shall content myself with writing out as follows; premising that the symbols stand for *edges* only, and exhibit, if read vertically, the faces, if read horizontally, the summits, of the solid; so that each figure may be viewed either as an 8-edron with triedral summits, or as a 12-edron with triangular faces. All polyedra can be presented to the eye in nearly the same manner, and this is perhaps the most elegant way of exhibiting them.

a b c d e f g - - - - -
m - - - - - a h i j k l
- - d r - - - - - k n -
- - - - - g h o - - - -
- - - e p - - - j r - -
- - - - f o - i p - - -
- c n - - - - - - - l q
b q - - - - - - - - - m

a b - c d e - f g - - -
k - - - - - - - a h i j
- c n r - - - - - - - -
- - - - - f p l - - - -
- - r d q - - - - - j o
- - - - e p m - - i q -
b n o - - - - - - - - k
- - - - - - l g h m - -

a b c d e - f g - - - -	*- - - d h i j k - - - -*
l - - - - - - a h i j k	*a - b c - - - d e f - g*
- c n - - - - - - - k m	*- l c h m - - - - - - -*
- - - - - o g h p - - -	*- - - - - - - k e n - - -*
- - d q - - - - - j n -	*r m - - i o - - - - - p a*
- - - e r p - - i q - -	*- - - - - j n - f q o -*
b m - - - - - - - - - l	*- - - - - - - - - - g q p*
- - - - f r o - - - - -	*b l r - - - - - - - - - -*

The rank of the faces is stated thus, in the order of rank,

7 7 4 4 4 4 3 3, 7 5 5 5 4 4 3 3,
7 6 5 4 4 4 3 3, 7 6 5 5 4 3 3 3.

The two last are the 8-edra (*a*) and (A) of (16) and (17).

In the above arrangements every duad of adjoining letters, as *dh* and *kd* in the pentagon *dhijk* of (A), which is read horizontally, is adjoined also vertically: *dh* is an angle in that pentagon, and the same edges *d* and *h* meet at the summit *dch*. The first and final letters of a multiplet are considered to be adjoining letters.

The total number of octaedra, whose summits are all triedral, is thus shown to be 14, viz., four on a heptagonal, eight on a hexagonal, and two on a pentagonal base; and the total number of 8-peaks having only triangular faces is 14, viz., four having a 7-edral, eight having a 6-edral, and two having a 5-edral summit.

The reader will gladly forego the consideration of the cases in which $n \gtrless 8$, to say nothing of the polyedra whose summits are not all triedral.

22. The geometrical problem—how many *n*-edrons are there?—reduces itself to the combinatorial problem:—In how many ways can multiplets, *i. e.*, triplets, quadruplets, &c., be made with *n* symbols, under these two conditions: first, that every contiguous pair of symbols in any multiplet shall be a contiguous pair in some one other, the first and last of a mul-

tiplet being reckoned a contiguous pair; secondly, that no three symbols of any multiplet shall occur in any other?

Every system of such multiplets made with n symbols represents a distinct n-edron, of which the faces, the summits, and the edges, can be assigned. If the symbols stand for faces, the multiplets are summits; and if the symbols contiguous to any symbol A be written out in order, as

$$aAb\ bAc\ cAd\ dAe\ eAf, \text{ \&c.,}$$

the edges about the face A are in order

$$aA\ bA\ cA\ dA,\ eA\ fA, \text{ \&c.}$$

If the symbols stand for summits, the multiplets are faces, and the edges in order about the summits are determined in exactly the same manner.

It is easy to deduce from Theo. I., that, if a_e be the number of e-gonal faces, and s_e that of the e-edral summits, of any p-edron, a_m and s_n being the number of the most-angled,

$$a_3+s_3-8-s_5-s_6- \ldots -s_{n-1}-s_n=a_5+2a_6+3a_7+ \ldots + (m-1-4)a_{m-1}+(m-4)a_m.$$

This affirms, that the total number of p-edrons, having a_3 triangular faces, and s_3 triedral, s_5 5-edral, . . . s_n n-edral, summits, and their most-angled face m-gonal, and differing in the numerical values of a_3, &c., and s_3, &c., *cannot exceed* that of the $(m-4)$-partitions of the number $M,=a_3+s_3-8-s_5-s_6- \ldots -s_n$; *i. e.*, of the ways in which M can be made up of $m-4$ numbers written in order; or, which is the same thing, if $m>3$, of the ways in which M can be divided into x parcels, none of which contains more than $m-4$, while one parcel at least contains $m-4$. The subindex 4 does not appear in the above equation: this is curious; but a geometrical reason can easily be assigned for its disappearance.

IV.—*Statistics of the Collieries of Lancashire, Cheshire, and North Wales.*

By Joseph Dickinson, F.G.S., Inspector of Coal Mines.

[*Read March 7th*, 1854.]

The number of collieries in the district comprising Lancashire, Cheshire, and North Wales, as set forth in the accompanying list, is 423. Of which

334	are in Lancashire,
28	in Cheshire,
5	in Anglesey,
30	in Flintshire, and
26	in Denbighshire.
423	Total.

The collieries are of various sizes. The smaller ones employ only a few hands, and the larger, from a thousand up to fifteen hundred persons. The output of coals per colliery varies from a few tons up to a third of a million tons per annum. The firm possessing the greatest interest in the coal trade of the district is that of Messrs. Andrew Knowles and Sons, the output of coal at whose collieries amounts to about two thousand four hundred tons per diem.

The number of working pits or shafts, exclusive of those used solely for air, is 879—besides 60 additional winnings by levels and inclined planes called "day eyes;" making a total of 939 separate winnings whereby coal is now being worked. The pits are of various depths up to 520 yards.

inches to about 10 feet; the greater proportion being between 3 feet and 7 feet. The dip of the beds varies from nearly level to an angle of 45 degrees, and sometimes more. Workings are in some cases carried on at the distance of 1,000 yards to the dip of the shaft, the produce being drawn up by engines placed on the surface or in the mines. Some of the mechanical arrangements for this purpose, and for the transit of coal down the steep inclines, are exceedingly ingenious and well worthy of imitation.

The method of working is long work and pillar and stall. Long work is common in North Wales, and is adopted in a few instances in Lancashire and Cheshire. The pillar and stall work of North Wales is known as "wicket work." The wickets or stalls vary in width up to 24 yards, and the pillars to 15 yards. The pillar and stall has various modifications. The common system is termed "straight ends and walls." The straight ends are drifts from 4½ feet to 6 feet wide, and the walls or pillars about 10 yards wide, varying according to circumstances. The process, when the system is properly carried out, is to drive first a pair of levels to the boundary, and there commence the straight ends for the pillar work; commencing to work the pillars at the boundary and working backwards towards the shaft, leaving the goaf behind. In this way each foot of the seam yields fully one thousand tons of large and mixed coals per statute acre. The system of working, in this way, from the extremities prevents waste by crushes or squeezes, and also simplifies the ventilation. Completing the levels before the end and pillar work is commenced has the effect of draining the seam of the greater part of its firedamp, when the workings are in the simplest form, and when almost any quantity of air can be directed to the most fiery points. Indeed, some of the very fiery seams are almost unworkable with safety by pillar and stall work, unless thus first drained of their firedamp. The ends alluded to are sometimes driven from 3 to 8 yards wide; and occasionally

they are worked simultaneously with the levels. The latter practice, however, almost invariably leads to a sacrifice of pillars; and it is worthy of remark, that during the past year the great explosions of firedamp in the Ince Hall coal and cannel works,* and Bent Grange collieries, both took place in mines worked upon this plan.

The ventilating powers used in the district are of great variety, comprising furnaces in the pit, and on the surface; chimneys connected with engine and other fires on the surface; boiler fires in the pits; steam jets, and discharged steam from surface and underground engines; waterfalls, and water jets; air pumps; and fans, worked by hand and steam engine. Whilst in a large number of instances, especially in cold weather, ventilation is carried on without artificial power.

The steepness of the seams in many of the mines of this district, especially of Lancashire and Cheshire, and the extent to which underground machinery is necessarily applied, render the working of the mines more than usually dangerous. The return of colliery accidents for this district for the years 1851, 1852, and 1853, show an average of 145 accidents, attended with the loss of 215⅔ lives per annum. This, at the rate of 38,000 persons employed, as ascertained for the intermediate year 1852, gives an average annual loss of $5\frac{33}{100}$ lives per thousand persons employed. A sacrifice which cannot be considered otherwise than exceedingly alarming.

In the Belgian coal mines, which in point of danger as regards steepness and firedamp, more closely resemble those of this district than other parts of Great Britain, the loss of life by accidents during the 5 years ending 1849 averaged only $3\frac{14}{100}$ per thousand. And even in the years 1851 and 1852, when accidents were more rife, it only amounted to

* Since this was written another great explosion has taken place in the same pit at this colliery.

Let C next appear with three duads of non-consecutive letters. We write the scheme with three triangles *b*, *d*, *f*,

A*ab* A*bc* A*cd* A*de* A*ef* A*fa*
abc *cde* *efa* *ac* *ce* *ea*.

We have three triplets to add containing C, which can be only C*ae* C*ce* C*ea*. These faces are

A C *a b c d e f*. (8)
6 3 6 3 6 3 6 3

There are thus found eight octaedra on a hexagonal base, having all their summits triedral.

18. We shall now examine the octaedra which have no face of more than five angles. There must then be two crowns.

Two crowns may in general be adnate by a common side, or connected by an intervening edge or broken ridge-line. If an intervening edge connects them, it is the side of a face at least hexagonal, if the summits are triedral; for that face must have two angles common with either crown besides two in the base. Our crowns, therefore, must be adnate at two summits; and the sum of their other summits cannot exceed five, because only one edge can pass to the pentagonal base from each of them.

Let the crowns be a pentagon C and a quadrilateral D. It is evident that between the two faces at the common summits of C and D there can intervene neither more nor less than one of the five faces about the base. Let *a* and *c* be the two. Then the triplets CD*a* CD*c* determine all the rest, for D must appear only twice more, and with every letter twice; thus—

A*ab* A*bc* A*cd* A*de* A*ea* CD*a* CD*c*
D*ab* D*bc* C*cd* C*de* C*ea*;

A C D *a b c d e*. (9)
5 5 4 5 4 5 4 4

19. When of two adnate crowns one is a triangle, there may intervene in general between the faces joining them at their common summits one or more faces, or none.

If the crowns of our octaedron are a pentagon C and a triangle D′, those faces at the common summits must be contiguous on the base, otherwise the summits would be angles of at least hexagons, containing each three angles on the two crowns, one in the face intervening between those non-contiguous faces, and two in the base. The common summits must therefore be CD′*a* CD′*b*.

We have to complete

A*ab* A*bc* A*cd* A*de* A*ea* CD′*a* CD′*b*
D′*ab* *bc* *cd* *de* *ea* C*a* C*b*.

As *a* and *b* cannot occur more than a fifth time, we must write C*ea* and C*bc*, whence of necessity C*ec* and *cde*.

This gives the faces

$$\begin{matrix} A & C & D' & a & b & c & d & e. \\ 5 & 5 & 3 & 5 & 5 & 5 & 3 & 5 \end{matrix} \qquad (10)$$

20. Two quadrilaterals, or a triangle and a quadrilateral, cannot be our two crowns, the base or most-angled face being pentagonal; for, as there must be seven summits out of the base, it will happen in either case that a face will contain three summits on the two crowns, two in the base, and one neither in the base nor the crowns. Two triangles cannot be adnate crowns, the summits being all triedral, because, of their common summits, only one can present to the base an angle less than two right angles; and that which is not less than two can be no angle in any face.

The base or most-angled face of an octaedron having only triedral summits cannot be less than pentagonal; for there must be 3×12 angles counted in all the faces, but $4\times8=32$ only.

I have thus found all the octaedra which have not a heptagonal face, and which have all their summits triedral. They may be collected briefly as follows:

(1) A C *a b c d e f*
6 6 4 4 4 4 4 4

(2) A C *a b c d e f*
6 5 5 4 4 4 5 3

(3) A C *a b c d e f*
6 4 5 4 4 6 3 4

(4) A C *a b c d e f*
6 4 5 4 5 3 6 3

(5) A C *a b c d e f*
6 4 5 5 3 5 5 3

(6) A C *a b c d e f*
6 3 6 4 6 3 5 3

(7) A C *a b c d e f*
6 3 6 4 5 5 3 4

(8) A C *a b c d e f*
6 3 6 3 6 3 6 3

(9) A C D *a b c d e*
5 5 4 5 4 5 4 4

(10) A C D *a b c d e*
5 5 3 5 5 5 3 5

The fourth and seventh of these have each two hexagons, two pentagons, two quadrilaterals, and two triangles; but they are different polyedra, their crowns being different when they are made to stand on hexagonal faces. Thus we see that a polyedron is not determined, when the angular rank of its faces and summits is given. The triplets which represent the summits of these octaedra will of course equally denote and describe the faces of those 12-edrons whose faces are all triangular, and which have no summit of more than six edges; if the letters *a*, *b*, *c*, &c. be taken for summits, not faces.

21. The remainder of the octaedra having triedral summits, namely, those on a 7-gonal base, I shall content myself with writing out as follows; premising that the symbols stand for *edges* only, and exhibit, if read vertically, the faces, if read horizontally, the summits, of the solid; so that each figure may be viewed either as an 8-edron with triedral summits, or as a 12-edron with triangular faces. All polyedra can be presented to the eye in nearly the same manner, and this is perhaps the most elegant way of exhibiting them.

a b c d e f g - - - - -
m - - - - - a h i j k l
- - d r - - - - - k n -
- - - - - g h o - - - -
- - - e p - - - j r - -
- - - - f o - i p - - -
- c n - - - - - - - l q
b q - - - - - - - - - m

a b - c d e - f g - - -
k - - - - - - - a h i j
- c n r - - - - - - - -
- - - - - f p l - - - -
- - r d q - - - - - j o
- - - - e p m - - i q -
b n o - - - - - - - - k
- - - - - - - l g h m - -

a b c d e - f g - - - -	*- - - d h i j k - - - -*
l - - - - - - a h i j k	*a - b c - - - d e f - g*
- c n - - - - - - - k m	*- l c h m - - - - - - -*
- - - - - o g h p - - -	*- - - - - - - k e n - - -*
- - d q - - - - - j n -	*r m - - i o - - - - p a*
- - - e r p - - i q - -	*- - - - - j n - f q o -*
b m - - - - - - - - - l	*- - - - - - - - - g q p*
- - - - f r o - - - - -	*b l r - - - - - - - - -*

The rank of the faces is stated thus, in the order of rank,

7 7 4 4 4 4 3 3, 7 5 5 5 4 4 3 3,
7 6 5 4 4 4 3 3, 7 6 5 5 4 3 3 3.

The two last are the 8-edra (*a*) and (A) of (16) and (17).

In the above arrangements every duad of adjoining letters, as *dh* and *kd* in the pentagon *dhijk* of (A), which is read horizontally, is adjoined also vertically: *dh* is an angle in that pentagon, and the same edges *d* and *h* meet at the summit *dch*. The first and final letters of a multiplet are considered to be adjoining letters.

The total number of octaedra, whose summits are all triedral, is thus shown to be 14, viz., four on a heptagonal, eight on a hexagonal, and two on a pentagonal base; and the total number of 8-peaks having only triangular faces is 14, viz., four having a 7-edral, eight having a 6-edral, and two having a 5-edral summit.

The reader will gladly forego the consideration of the cases in which $n > 8$, to say nothing of the polyedra whose summits are not all triedral.

22. The geometrical problem—how many n-edrons are there?—reduces itself to the combinatorial problem:—In how many ways can multiplets, *i. e.*, triplets, quadruplets, &c., be made with n symbols, under these two conditions: first, that every contiguous pair of symbols in any multiplet shall be a contiguous pair in some one other, the first and last of a mul-

inches to about 10 feet; the greater proportion being between 3 feet and 7 feet. The dip of the beds varies from nearly level to an angle of 45 degrees, and sometimes more. Workings are in some cases carried on at the distance of 1,000 yards to the dip of the shaft, the produce being drawn up by engines placed on the surface or in the mines. Some of the mechanical arrangements for this purpose, and for the transit of coal down the steep inclines, are exceedingly ingenious and well worthy of imitation.

The method of working is long work and pillar and stall. Long work is common in North Wales, and is adopted in a few instances in Lancashire and Cheshire. The pillar and stall work of North Wales is known as "wicket work." The wickets or stalls vary in width up to 24 yards, and the pillars to 15 yards. The pillar and stall has various modifications. The common system is termed "straight ends and walls." The straight ends are drifts from 4½ feet to 6 feet wide, and the walls or pillars about 10 yards wide, varying according to circumstances. The process, when the system is properly carried out, is to drive first a pair of levels to the boundary, and there commence the straight ends for the pillar work; commencing to work the pillars at the boundary and working backwards towards the shaft, leaving the goaf behind. In this way each foot of the seam yields fully one thousand tons of large and mixed coals per statute acre. The system of working, in this way, from the extremities prevents waste by crushes or squeezes, and also simplifies the ventilation. Completing the levels before the end and pillar work is commenced has the effect of draining the seam of the greater part of its firedamp, when the workings are in the simplest form, and when almost any quantity of air can be directed to the most fiery points. Indeed, some of the very fiery seams are almost unworkable with safety by pillar and stall work, unless thus first drained of their firedamp. The ends alluded to are sometimes driven from 3 to 8 yards wide; and occasionally

they are worked simultaneously with the levels. The latter practice, however, almost invariably leads to a sacrifice of pillars; and it is worthy of remark, that during the past year the great explosions of firedamp in the Ince Hall coal and cannel works,* and Bent Grange collieries, both took place in mines worked upon this plan.

The ventilating powers used in the district are of great variety, comprising furnaces in the pit, and on the surface; chimneys connected with engine and other fires on the surface; boiler fires in the pits; steam jets, and discharged steam from surface and underground engines; waterfalls, and water jets; air pumps; and fans, worked by hand and steam engine. Whilst in a large number of instances, especially in cold weather, ventilation is carried on without artificial power.

The steepness of the seams in many of the mines of this district, especially of Lancashire and Cheshire, and the extent to which underground machinery is necessarily applied, render the working of the mines more than usually dangerous. The return of colliery accidents for this district for the years 1851, 1852, and 1853, show an average of 145 accidents, attended with the loss of 215⅔ lives per annum. This, at the rate of 38,000 persons employed, as ascertained for the intermediate year 1852, gives an average annual loss of $5\frac{33}{100}$ lives per thousand persons employed. A sacrifice which cannot be considered otherwise than exceedingly alarming.

In the Belgian coal mines, which in point of danger as regards steepness and firedamp, more closely resemble those of this district than other parts of Great Britain, the loss of life by accidents during the 5 years ending 1849 averaged only $3\frac{14}{100}$ per thousand. And even in the years 1851 and 1852, when accidents were more rife, it only amounted to

* Since this was written another great explosion has taken place in the same pit at this colliery.

$4\frac{8}{100}$ per thousand; being in both cases less than the per centage of this district.

In comparing the colliery accidents of this district with those of Belgium, it is, however, important to know that in proportion to the quantity of coals raised a much larger number of persons are employed at the Belgian coal mines; and that of those employed, a larger proportion of them are on the surface, where they are out of danger. One great point of difference being, that in Lancashire and Cheshire machinery is extensively used underground for drawing the produce; whilst such work is carried on in the Belgium collieries chiefly by male and female labor.

In comparing the per centage of accidents, therefore, it seems proper to look not only at the risk per head but also at the amount of work performed, and in this respect it is satisfaction to know that the collieries of this district present a favorable comparison. The average annual get or quantity of coal raised per person employed in this district being nearly double that of Belgium.

The output of coals in Belgium during the 5 years ending 1849 alluded to, averaged 5,055,196 English tons per annum, and the deaths from accidents $144\frac{4}{5}$ per annum, the average was consequently at the rate of 1 life lost for every 34,911 tons raised. And in the years 1851 and 1852, when the deaths from accidents averaged $194\frac{1}{2}$, the average was at the increased rate of about 1 life for every 31,000 tons.

In the Lancashire, Cheshire, and North Wales district, the number of lives lost during the years 1851, 1852, and 1853, averaged $215\frac{2}{3}$, and the output of coals, as ascertained for the intermediate year 1852, 9,923,000 tons per annum; the per centage of deaths by accidents was consequently at the rate of 1 life per 46,010 tons of coal raised. A comparison with Belgium in point of work done is therefore much in favor of this district.

The loss of life to persons employed in and about the

whole of the collieries of Great Britain, as ascertained for 1851 and 1852, averaged 985 per annum. The total output of coals is not correctly known, but it may be stated at not less than 54,000,000 tons; the average loss of life, therefore, at this estimate, for the whole of Great Britain, is 1 life for 54,822 tons of coal. In previous years the mortality was probably greater, many improvements as to the health and safety of the miner having been introduced into collieries by the passing of the act for the inspection of coal mines in 1850. Our leading collieries, so far as I can judge, are at present in advance of continental coal mines. A large proportion, however, have many evident defects which admit of being removed; and doubtless some proportion of the appalling list of casualties may be classed as preventible accidents, which it is to be hoped may shortly be dealt with accordingly.

Funds for relief in sickness are seldom carried on in connexion with the collieries of this district; the workmen apparently preferring the entire management of such affairs in their own hands. Benefit societies amongst the workmen are numerous; and most workmen belong to one or more of them. In cases where sick funds exist in connexion with the colliery, and joining is optional, few of the men are said to join. In one case an old-established fund was brought to a forced conclusion by a strike in 1845, the weekly stoppage for the fund being objected to as a violation of the "Truck Act."

Funds for relief in case of accident are more numerous; and at most collieries medical attendance on accidents is provided either gratuitously by the colliery owner, or by a small weekly stoppage from the workman's wages. Medical attendance in ordinary sickness is provided by the colliers themselves or in connexion with their benefit societies.

Considering the numbers engaged in the coal trade of this district, the education of the collier's children deserves special attention. Colliers, as a body, are perhaps less alive than

most classes of skilled workmen to the importance of education. Parochial and national schools are numerous, and may be reached almost invariably within two miles of the collier's dwelling, but few miners' children are said to attend.

The following comprises the information which I have obtained as to the efforts made by the colliery owners of this district to promote the education of their workpeople.

Kirkless Colliery; Mr. Thicknesse, M.P. A school is supported by the owner, the number of children being limited to 70, which appears a sufficient number for the wants of the place.

Gidlow and Swinley Colliery; the Executors of the late Joseph Rylands. A school building and a portion of the books is provided by the proprietors, who also pay £20. per annum towards the teacher's salary. Each scholar pays twopence per week to the teacher besides.

Messrs. William Hill Brancker and Co.; Bispham Colliery, subscribe to schools in the neighbourhood.

Bickershaw Colliery; Messrs. Ackers, Whitley, and Co. A school is supported partly by children's pence, the remainder by the company.

Haydock Colliery; Messrs. Richard Evans and Co. A school supported partly by the owners and partly by children's pence.

Astley and Tyldesley Collieries; Messrs. Sam Jackson and Co., subscribe to Astley Free School, and can send 8 children.

Burnley, Habergham, Marsden, and Padiham Collieries; the Executors of the late John Hargreaves. A school supported partly by the colliery and part by voluntary subscription—about 70 children attend.

Hopwood Colliery; Mr. Robert Gregg Hopwood. No school actually attached, but several greatly supported by people connected with the works, and many of the men and boys attend.

Halsnead Colliery; Mr. Richard Willis. A school built by Mr. Willis and supported by contributions—average attendance 84 boys, 78 girls.

Ravenhead Colliery; Messrs. Bromilow, Haddock, and Co. A school attached to the works and supported partly by the owners, and partly by the children's pence. About 82 children attend, and each contributes from 2d. to 4d. per week.

Worsley Colleries; the Bridgewater Trustees. Eight schools in the immediate neighbourhood are almost wholly supported by the Earl of Ellesmere, which are more or less accessible to the children of the colliers—besides libraries and reading rooms. Probably 800 children connected with the colliers attend the schools.

Clifton Colliery; the Trustees of the late Ellis Fletcher. A school and a chaplain provided.

In Cheshire. At the Norbury Colliery; Messrs. Clayton and Brooke pay for 34 of the children of their workmen against the same number sent by the parents of the same children. One being sent by the colliery owners against one by the parents, who go to the National Schools of Norbury and High Lane.

Poynton and Worth Collieries. A free school supported by Lord Vernon. Number of children attending school—boys, day school 105, Sunday school 133—girls and infants, day school 242, Sunday school 171.

In North Wales, none.

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OF

COLLIERIES IN LANCASHIRE, CHESHIRE, AND NORTH WALES.

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Burnley	14	
Bury	11	
Chorley	7	
Leigh	15	
Manchester	15	
Oldham	28	
Rainford	10	
Rochdale, including Bacup and Rossendale	84	
St. Helens	25	
Wigan	54	
		— 334
Cheshire		28
Anglesey		5
Flintshire		30
Denbighshire		26
Total Collieries		423

LIST OF COLLIERIES IN LANCASHIRE, CHESHIRE, AND NORTH WALES.

ASHTON UNDER-LYNE.

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
1. Bardsley	Bardsley	Jonah Harrop.
2. Bardsley	Bardsley	Jonah Harrop and Co.
3. Charlestown	Ashton-under-Lyne	William Wild.
4. Fairbottom	Fairbottom, &c.	Leese and Booth.
5. Heys	Ashton-under-Lyne	John Kenworthy and brothers.
6. Hurst Knowl	Ashton-under-Lyne	John Whitaker and Sons.
7. Limehurst	Bardsley	John George Newton.

BLACKBURN.

1. Bank Moor	Oswaldtwistle	Simpson and Young.
2. Baxenden	Accrington	Hargreaves, Ashworth, and Co.
3. Broadfield	Accrington	Simpson and Young.
4. Brookside	Accrington	Simpson and Young.
5. Clayton	Clayton	John Lomax.
6. Coney	Over Darwen	William Pierce.

BLACKBURN.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
7. Dogshaw	Over Darwen	Eccles Shorrock.
8. Duckworth Hall	Oswaldtwistle	Simpson and Young.
9. Dunkenhalgh Park	Church	Joseph Barnes.
10. Dunkirk	Henfield	John Lomax.
11. Ellison Fold	Over Darwen	John and James Brandwood.
12. Flash	Eccleshill	William Brandwood.
13. Higher Cunliffe Brick Works	Rishton	Higher Cunliffe Brick Works Company.
14. Hoddlesden	Over Darwen	John and Joseph Place.
15. Lower Barn	Over Darwen	James and George Shorrock.
16. Marsh House	Over Darwen	John and William Pickup.
17. Old Lyons	Over Darwen	Scholes and Fish.
18. Pole	Over Darwen	William Pickup.
19. Pole Lane	Sough...	James Pickup.
20. Rishton Height	Over Darwen	James and George Shorrock.
21. Scholes Fold	Over Darwen	John and James Brandwood.

BOLTON.

1. Ainsworth Red House	Ainsworth	Thomas Fletcher.
2. Affeside	Tottington	Jethro Scowcroft.
3. Albert	Westhoughton	William Barton.
4. Arley	Blackrod	
5. Bank	Little Hulton	Thomas Wright.
6. Bank House	Middle Hulton	Francis Charlton.
7. Bents	Little Lever	Thomas Fletcher.
8. Blackrod	Blackrod	Charles and Thomas Whaley and Co.
9. Bull Ring	Blackrod	F. G. Dutton and Co.
10. Burnden	Bolton	Thomas, Samuel, and Executors of late John Scowcroft.
11. Breightmet	Breightmet	James Hardcastle.
12. Breightmet	Breightmet	Thomas Fletcher.
13. Darcy Lever	Darcy Lever	Darcy Lever Coal Company.
14. Dark Lane	Blackrod	James Massey.
15. Doffcocker	Halliwell	Longworth and Scowcroft.
16. Farnworth	Farnworth	William Crompton.
17. Five Quarter	Great Lever	John Smith, jun., and Co.
18. Great Lever	Great Lever	Right Hon. Earl of Bradford.

BOLTON.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
19. Hacken	Little Lever	Andrew Knowles and Sons.
20. Hanging Bank	Little Hulton	James Kay and Co.
21. Harwood	Harwood	James Hardcastle.
22. Hulton	Over and Middle Hulton and Farnworth	William Hulton.
23. Kearsley	Farnworth	Thomas, Samuel, and Executors of late John Scowcroft.
24. Ladyshore	Little Lever	John Fletcher.
25. Little Bolton	Little Bolton	Andrew Knowles and Sons.
26. Little Hulton	Little Hulton	Matthew Bennett and brothers.
27. Little Lever	Little Lever	Andrew Knowles and Sons.
28. New Fields	Horwich	John M. Walch.
29. New Watergate	Little Hulton	James and William Roscow.
30. Quarlton	Quarlton	Andrew Knowles and Sons.
31. Smithfold	Little Hulton	John Gibson and Co.
32. Smithills	Halliwell	Peter Ainsworth.
33. Stoneclough	Kearsley	Thomas Grundy.

34.	Stoneclough	Kearsley	Knowles and Stott.
35.	Stopes	Little Lever	Thomas Fletcher.
36.	Tonge	Tonge	Robert Burton and Son.
37.	Top-o'-th-Lane	Darcy Lever	Andrew Knowles and Sons.
38.	Turton Moor	Turton	Andrew Knowles and Sons.
39.	Unity Brook	Kearsley	James Stott.
40.	Victoria Main	Blackrod	John Ridgway and Co.
41.	West Houghton	West Houghton	Longworth and Scowcroft.
42.	Willows	Horwich	Brownlow and Radcliffe.
43.	Winter Hill	Horwich	Adam Mason.

BURNLEY.

1.	Altham New	Altham	Hallam and Fawcett.
2.	Burnley	Burnley	Executors of late John Hargreaves.
3.	Burnt Hills	Hapton	Executors of late John Hargreaves.
4.	Cliviger	Cliviger	Cliviger Coal Company.
5.	Cupola	Hapton	Brooks and Pickup.
6.	Dodbottom	Holme Chapel	Thomas H. Whitaker.
7.	Fulledge	Burnley	William Cardwell and Co.

BURNLEY.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
8. Habergham	Habergham Eaves	Executors of late John Hargreaves.
9. Hapton	Hapton	Hapton Coal Company.
10. Hapton Valley	Hapton	Executors of late John Hargreaves.
11. Horse Pasture	Towneley	Charles Towneley, Esq.
12. Marsden	Marsden	Executors of late John Hargreaves.
13. Padiham	Padiham	Executors of late John Hargreaves.
14. Town House	Great Marsden	Spencer, Wilson, and Co.

BURY.

1. Cockey Moor	Radcliffe	James Knowles.
2. Dark Lane	Walmersley	Laurence Duckworth.
3. Elton	Elton	William Thornton Parks.
4. Fern Hill	Bury	William Walker and Co.
5. Higher Hill	Shuttleworth	Laurence Duckworth.
6. Holcombe	Holcombe Hill	Holcombe Brickwork Company.
7. Radcliffe Bridge & Bank Top	Radcliffe	Knowles and Hall.
8. Ringley and Clough Side	Prestwich	Bromilow, Brownbill, and Co.

9. Scout Moor	Shuttleworth	Laurence Duckworth.
10. Stand Lane	Radcliffe Bridge	Thomas Grundy and brother.
11. Woodgate Hill	Bury	John Holt and Co. (Bamford, Haigh, and Co.)

CHORLEY.

1. Charnock	Charnock Richard	John Smith.
2. Chorley	Chorley	Jonathan Blundell and Son.
3. Coppull and Burgh	Coppull	John Hargreaves, jun.
4. Duxbury	Duxbury	T. and W. Whittle.
5. Heath Charnock	Heath Charnock	John Rosebottom.
6. Railway	Charnock Richard	Executors of late John Darlington.
7. Yarrow	Duxbury	Thomas Whaley.

LEIGH.

1. Astley and Tyldesley	Astley	Sam Jackson and Co.
2. Atherton	Atherton	John Fletcher and others.
3. Bedford	Bedford	Sam Jackson and Co.
4. Broadfield	Westleigh	John Speakman and Co.
5. Edge Green	Golborne	Richard Evans and Sons.
6. Great Boys	Tyldesley	William Atkin.

LEIGH.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
7. Hey Field	Westleigh	Thomas Livesey.
8. Park	Westleigh	Trustees of the Liverpool and Manchester Coal Company.
9. Peel	Tyldesley	Thomas Grundy.
10. Pickley Heys	Westleigh	Thomas Lowe and Co.
11. Shakerley	Tyldesley	Nathan Eckersley.
12. Springfield	Westleigh (and Wigan)	Farington, Marshall, and Co.
13. Tyldesley	Tyldesley	Tyldesley Coal Company.
14. Westleigh	Westleigh	James Diggle and Co.
15. Westleigh Lane	Westleigh	Samuel Banks.

MANCHESTER.

1. Agecroft	Pendlebury	Andrew Knowles and Sons.
2. Bradford	Bradford	Bradford Coal Company.
3. Clayton	Clayton	Leigh and Bradbury.
4. Clifton and Kearsley	Clifton	Trustees of late Ellis Fletcher.
5. Clifton Hall	Clifton	Andrew Knowles and Sons.

6.	Clifton Moss	Clifton	Andrew Knowles and Sons.
7.	Denton	Denton	Jacob Fletcher Fletcher.
8.	Denton	Denton	Peter Higson.
9.	Haughton	Haughton	Leigh and Bradbury.
10.	Haughton	Haughton	Thomas Shaw.
N 11.	Mesne Lea	Worsley	Representatives of late Peter Nightingale.
12.	Moston	Moston	John Stanley.
13.	Pendlebury	Pendlebury	Andrew Knowles and Sons.
14.	Pendleton	Pendleton	Andrew Knowles and Sons.
15.	Worsley	Worsley, &c.	Bridgewater Trustees.

OLDHAM.

1.	Bank House	Crompton	Executors of late Charles Taylor.
2.	Barrowshaw	Oldham	Job Lees.
3.	Beesom Hill	Oldham	James Wilson.
4.	Beesom Hill	Oldham	James Taylor.
5.	Bent Grange	Oldham	Thomas Butterworth.
6.	Browns	Crompton	Joseph and Thomas Mills.
7.	Chadderton	Oldham	William Jones and Co.

OLDHAM.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
8. Chamber	Oldham	William Jones and Co.
9. Count Hill	Oldham	Job Lees.
10. Doghill	Crompton	Joseph Cook and John Marland.
11. Edge Lane and Dry Clough	Oldham	Evans, Barker, and Co.
12. Glodwick	Oldham	James Collinge and Co.
13. Greenacres	Oldham	Leese and Booth.
14. Hey	Oldham	Mills, Lees, and Co.
15. Higginshaw Lane	Royton	Milne, Travis, and Milne.
16. Hodge Clough	Oldham	Jesse Ainsworth.
17. Holebottom	Oldham	Lees', Jones, and Co.
18. Holebottom	Crompton	Executors of late Charles Taylor.
19. Jubilee	Crompton	Evans, Barker, and Co.
20. Low Crompton	Crompton	James Stott Milne and Co.
21. Low Side	Oldham	William Wrigley.
22. Oak	Oldham	William Jones and Co.
23. Park	Crompton	Evans, Barker, and Co.
24. Paulden Wood	Oldham	Mills, Lees, and Co.

25. Sholver Fold	Oldham	Abraham Lees.
26. Sholver Moor	Oldham	James Buckley.
27. Sholver Moor	Oldham	George Hallas.
28. Turf Pits	Oldham	Job Lees.

RAINFORD.

1. Albert	Upholland	Holdsworth and Co.
2. Bickerstaffe	Bickerstaffe	Bromilow, Forster, and Co.
3. Bickerstaffe	Bickerstaffe	Trustees of late Lord Skelmersdale.
4. Holland	Upholland	Earl of Crawford and Balcarres.
5. Lathom	Lathom	Trustees of late Lord Skelmersdale.
6. New Gate	Upholland	Thomas Rigby.
7. Rainford	Rainford	William Harding.
8. Skelmersdale	Skelmersdale	Mrs. Mary Stopforth.
9. Tower Hill	Upholland	John Cadman.
10. Victoria	Rainford	Holdsworth and Co.

ROCHDALE.

INCLUDING BACUP AND ROSSENDALE.

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
1. Ashworth	Ashworth	Robert Lees, James Greenwood, & James Lord.
2. Bagslate	Bagslate, Chadwick	James Lord and Samuel Wild.
3. Baitings	Wolstenholme	William Booth.
4. Bank Top	Bacup	Thomas Watson and Co.
5. Birchen Lee	Butterworth	John Knowles and Co.
6. Birtle Dean	Ashworth	Ramsbottom and Golding.
7. Blue Ball	Brandwood, Bacup	James Butterworth and Co.
8. Bowling Green	Birtle Detached	Greenwoods, Baron, and Tattersall.
9. Brearley	Butterworth	Henry Brearley.
10. Brex	Newchurch, Rossendale	Hargreaves, Ashworth, and Co.
11. Brotherod	Catley Lane	H. H. Fishwick and Co.
12. Brownhill	Catley Lane	Charles Lomax and James Lord.
13. Brownhouse	Healey	James Dearden.
14. Captain Fold	Heywood	Heywood Coal Company.
15. Cartridge Nook		James Dearden.
16. Chadwick Hall	Chadwick	Roscow and Lord.

17. Cheesden Lumb	Wolstenholme	John Howarth.
18. Clap Gate	Woodhouse Lane	Zechariah Howarth and John Brearley.
19. Clegswood	Butterworth, Littleborough.	
20. Clough Head Brick Works	Todmorden	Thomas Temperley.
21. Croft Head	Butterworth	Croft Head Company.
22. Dean		James Stott Milne and Co.
23. Dean	Newchurch, Rossendale	Hargreaves, Ashworth, and Co.
24. Drybank	Whitworth	James Duckworth and Co.
25. Eales	Blatchinworth, Littleboro'	Thomas Ferrand Dearden.
26. Fordoe	Wolstenholme	James Butterworth.
27. Foulclough	Todmorden	John and Reuben Haigh.
28. Freeholds	Whitworth	Haigh.
29. Greave	Brandwood, Bacup	Townsend, Hargreaves, and Barlow.
30. Greave Brick Works	Brandwood, Bacup	Taylor and Hoyle.
31. Green's Moor	Brandwood, Bacup	Robert Munn.
32. Hanging Chadder	Thornham	James Stott Milne and Co.
33. Hathershaw	Thornham	James Stott Milne and Co.
34. Healey Hall	Healey Hall	Jacob Tweedale and Sons.
35. Hogshead	Whitworth, Bacup	Robert Lees.
36. Hogshead	Whitworth, Bacup	Townend, Maden, and Lord.

ROCHDALE.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
37. Hopwood	Hopwood, Middleton	Robert Gregg Hopwood.
38. Hoyle Hey	Brandwood, Bacup	James Greenwood.
39. Knowl	Wolstenholme	George Howarth.
40. Knowsley	Whitworth	Joah Townend.
41. Land	Whitworth	James Dearden.
42. Lidgate	Blatchinworth, Littleboro'	Phillippi, Sutcliffe, Leo, and Co.
43. Little Green aud Scowcroft	Middleton	Wyld, Andrews, and Co.
44. Meadow Croft	Heap Detached, near Chadwick	Roscow and Lord.
45. New Hey	Brandwood, Bacup	Aitkin brothers.
46. Nook		Fishwick and Co.
47. Oaken Clough	Brandwood, Bacup	James Butterworth.
48. Old Clough	Newchurch, Rossendale	Hargreaves, Ashworth, and Co.
49. Old Hey	Brandwood, Bacup	Townsend, Hargreaves, and Barlow.
50. Old Meadows	Newchurch, Rossendale	Hargreaves, Ashworth, and Co.
51. Old Sink	Rooley Moor, Brandwood	Townsend, Hargreaves, and Barlow.
52. Openshaw	Birtle	Joseph Chadwick.

53. Pikehouse	Blatchinworth, Littleboro'	Phillippi, Sutcliffe, Leo, and Co.
54. Pilsworth	Pilsworth	Fletcher and Whewell.
55. Red Lumb	Wolstenholme	Thomas Shepherd.
56. Rooley Moor	Brandwood	Executors of late George Ormerod.
57. Rooley Moor	Brandwood	Richard Ashworth.
58. Schofield Hall	Butterworth	James Fielding and John Whittles.
59. Shaw Bank	Butterworth	J. and W. Chadwick.
60. Shaw Field	Catley Lane	James Stott and James Jackson.
61. Shaw Moss	Butterworth	John Knowles, jun., and Co.
62. Shore Lane	Butterworth	J. and W. Chadwick.
63. Smallbridge	Wardle	Stotts', Dearden, and Lomax.
64. South Grain	Todmorden	James Dearden.
65. Swinshaw	Newchurch, Rossendale	Hargreaves, Ashworth, and Co.
66. Thistley Field	Butterworth	John Knowles and Co.
67. Thorney Hurst	Birtle	Roscow and Lord.
68. Toadleach	Healey	James Dearden.
69. Todmorden Moor	Todmorden	James Dearden.
70. Tonge Lane	Middleton	Whitehead and Andrews.
71. Tonacliffe	Whitworth	John Lord.
72. Tonacliffe Level	Whitworth	James Walton.

ROCHDALE.—*Continued.*

NAME OF COLEIERY.	WHERE SITUATE.	OWNER'S NAME.
73. Tooter Hill	Brandwood, Bacup	James Dearden.
74. Tooter Hill	Brandwood, Bacup	James Law.
75. Turf House	Blatchinworth, Littleboro'	Bamford and Co.
76. Turf Tavern	Chadwick, Bagslate	John and George Mills.
77. Wallnook		James Dearden.
78. Whitaker	Butterworth	Edmund Turner Lord.
79. Whitaker New	Butterworth	Rigby and Lees.
80. Whitwell Bottoms	Newchurch, Rossendale	Hargreaves, Ashworth, and Co.
81. Wolstenholme Fold	Wolstenholme	Hall and Urmson.
82. Wolstenholme Hall	Wolstenholme	Thomas Shepherd.
83. Woodhouse Lane	Woodhouse Lane	Zechariah Howarth.
84. Woodhouse Lane	Woodhouse Lane	John Buckley.

ST. HELENS.

1. Ashton and Pewfall	Ashton-in-Makerfield	Samuel Clough and Co.
2. Ashton Green	Parr	Ashton Green Colliery Company.
3. Black Brook	Parr	Bromilow, brother, and Sothern.

4. Blackleyhurst	Ashton-in-Makerfield (and Wigan)	Samuel Stock.
5. Broad Oak	Parr	Bournes and Robinson.
6. Bryn	Ashton-in-Makerfield	William Garstang and Son.
7. Cowley Hill	Windle	Caldwell and Thomson.
8. Cropper's Hill	Eccleston	James Radley.
9. Gerard's Bridge	Windle	Caldwell and Thomson.
10. Gin Lane	Eccleston	David Bromilow and Co.
11. Glade Hill	Parr	John and Thomas Johnson.
12. Halsnead	Whiston	Richard Willis.
13. Haydock	Ashton-in-Makerfield	Richard Evans and Sons.
14. High Brooks	Ashton-in-Makerfield	Wright, Taylor, and Mercer.
15. Laffak	Parr	John and Thomas Johnson.
16. Parr Stocks	Parr	Johnson, Werninck, and Co.
17. Prescot	Prescot	John Yates and Co.
18. Prescot Brook	Huyton	David Bromilow and Co.
19. Ravenhead	Sutton	Bromilow, Haddock, and Co.
20. Riding Lane	Ashton-in-Makerfield	Joseph Ashton.
21. Royal	Eccleston	David Bromilow and Co.
22. Sankey Brook	Parr	Sankey Brook Colliery Company.

ST. HELENS.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
23. Sutton	Sutton	Bournes and Robinson.
24. Union	Eccleston	James Radley.
25. Whiston, or Paradise	Whiston, near Prescot	John Yates and Co.

WIGAN.

1. Albion	Hindley	John Thomas Wood.
2. Almond Brook	Standish	John Taylor.
3. Amberswood	Ince-in-Makerfield	Jonathan Blundell and Son.
4. Bickershaw	Abram (and Leigh)	Ackers, Whitley, and Co.
5. Birkett Bank	Wigan	James Lancaster.
6. Bispham	Billinge	William Hill Brancker and Co.
7. Bottling Wood	Wigan	John Part.
8. Bradley	Standish	Richard Fisher.
9. Bradshaw Hall	Aspull	Wright and Taylor.
10. Bradshaw House	Aspull	John Johnson.
11. Broomfield	Standish	Broomfield Colliery Company.
12. Chapel Green	Hindley	John Bleasdale.

13. Clap Gate	Pemberton	Henry Harrison.
14. Douglas Bank	Wigan	John Ashton Case.
15. Four Lane Ends	Shevington	William Barton.
16. Gidlow	Wigan	Alexander Fowden Halliburton.
17. Gidlow and Swinley	Wigan	Executors of late Joseph Rylands.
18. Haigh	Haigh, &c.	Earl of Crawford and Balcarres.
19. Hawkley	Pemberton	
20. Hindley Green	Hindley	John Scowcroft and Co.
21. Hindley Green	Hindley	Robert Worsley.
22. Holme House	Wigan	Henry Woods.
23. Hosier House	Ince-in-Makerfield	Thomas Gidlow.
24. Ince	Ince-in-Makerfield	Alexander Fowden Halliburton.
25. Ince Hall	Ince-in-Makerfield	Executors of late J. Whaley.
26. Ince Hall Coal and Cannel Works	Ince and Wigan	Ince Hall Coal and Cannel Company.
27. Kirkless	Aspull	Ralph A. Thicknesse, M.P.
28. Kirkless Hall	Aspull	John Lancaster and Co.
29. Little Westwood	Ince-in-Makerfield	Kay and James.
30. Low Hall	Hindley	Moss Hall Coal Company.
31. Meadow's House	Wigan	Anthony Eccles.

WIGAN.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NANE.
32. Mesnes	Wigan	Jonathan Blundell and Son.
33. Moss Hall	Ince-in-Makerfield	Moss Hall Coal Company.
34. Moss Hall	Ince-in-Makerfield	Nuttall and Caldwell.
35. Moss House	Pemberton	Executors of late J. Whaley.
36. New Town	Pemberton	Jonathan Lamb.
37. Norley Hall	Pemberton	Executors of late John Daglish.
38. Pemberton	Pemberton	John Stephen.
39. Pemberton	Pemberton	Jonathan Blundell and Son.
40. Platt Bridge	Ince-in-Makerfield	
41. Platt Lane	Wigan	Wright and Taylor.
42. Rose Bridge	Wigan	Case and Morris.
43. Shevington	Shevington	John Tayleur and Co.
44. Smith's Lane	Abram	Tickle and Co.
45. Sovereign Mill	Wigan	Woods and Co.
46. Spring	Ince-in-Makerfield	Thomas Pearson.
47. Standish Lower Ground	Standish	John Taylor.
48. Strangeways Hall	Hindley	Strangeways Hall Coal Company.

49.	Victoria	Standish	John Taylor.
50.	Waites Delf	Pemberton	Craig.
51.	Walthewhouse	Pemberton	William Hill Brancker & Co.
52.	Whelley	Wigan	Jonathan Lamb.
53.	Winstanley	Winstanley	Meyrick Banks.
54.	Wrightington	Wrightington	Charles Scarisbrick.

CHESHIRE.

1.	Back Lane	Newton	Executors of late George Wooley.
2.	Bakestonedale	Pott Shrigley	Matthew Gaskell.
3.	Bayleyfield	Mottram	Thomas, James, and John Ashton.
4.	Berestow Day Eye	Pott Shrigley	Peter Vere, jun.
5.	Bredbury Black Mine	Bredbury	J. and J. Jowett.
6.	California Day Eye,	Rainow	Peter Vere, sen.
7.	Dane	Wildboarclough	Thomas Speakman.
8.	Dukinfield	Dukinfield	Dukinfield Coal Company.
9.	Dukinfield	Dukinfield	F. D. P. Astley.
10.	Dunkirk	Dukinfield	Dunkirk Coal Company.
11.	Hockerley	Whaley	Thomas Srigley.

CHESHIRE.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
12. Hough Hole Day Eye	Rainow	Jesse Ainsworth.
13. Hyde	Hyde	Leigh and Bradbury.
14. Lower Spond's Day Eye ...	Lyme	John Johnson.
15. Lymer Clough.....	Rainow	Humphrey Swindells.
16. Macclesfield Common.....	Macclesfield	Executors of late Charles Cook.
17. Middle Cale.....	Lyme	Representatives of late Thomas Brocklehurst.
18. Ness	Great Neston-on-the-Dee...	Rowland Errington.
19. Norbury	Norbury	Clayton and Brooke.
20. One House	Macclesfield	Jaspar Hooley.
21. Pott Brick Works	Pott Shrigley	George Lambert.
22. Poynton and Worth	Poynton	The Hon. Lord Vernon.
23. Roe Wood	Macclesfield	George Needham.
24. Sponds	Lyme	James Jackson.
25. Sponds	Lyme	Job Ennion.
26. Staley Bridge	Staley Bridge	Executors of late George Wooley.
27. Whaley.....	Texal	John William Boothman.
28. Woodend Day Eye.....	Disley.....	Ralph Bower.

ANGLESEY.

1. Berw	Llanidan, Berw	Anglesey Coal Company.
2. Berw y Chaf	Llanfihangel, Berw	Hugh Hughe and Son.
3. Glantreath	Trefdraith, Berw	Hugh Hughe and Son.
4. Pont Marquis	Trefdraith, Berw	Pont Marquis Colliery Company.
5. Tai Herion	Llanfihangel, Berw	Hugh Hughe and Son.

FLINTSHIRE.

1. Alltami	Northope, near Mold	Catheral and Co.
2. Bagillt	Bagillt, Holywell	Wilson, Maxwell, and Co.
3. Bath	Flint	Charles Dean.
4. Bistre	Mold	Samuel Jones.
5. Broncoed	Mold	Lloyd and Shepherd.
6. Bromfield	Mold	Rev. Benjamin Crompton.
7. Bryn	near Mostyn, Llanassa	Edward Price and Co.
8. Bryn Goleu	Flint	R. Jones and David Jones, &c.
9. Bryn y Bil	Mold	Bryn y Bil Company.
10. Buckleigh	Hawarden	John Williams and others.
11. Coed Talon and Leeswood	Mold	Edward Oakley.

FLINTSHIRE.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
12. Coleshill	Bagillt, Holywell	William Jones and Co.
13. Coppy Hartsath	Pont Blyddyn, Mold	Coppy Colliery Company.
14. Cornist	Flint	Bolton and Swindells.
15. Englefield and Trevor	Holywell	Parry, Jones, and Co.
16. Ewloe	Hawarden	Hancock and Co.
17. Ewloe	Hawarden	John Williams and others.
18. Flint	Flint	Eyton brothers.
19. Flint Marsh and Gwaithycoed	Flint	Flint Marsh Colliery Company.
20. Galchog	Northope, Mold	Bolton and Swindells.
21. Mold Town	Mold	Mold Town Colliery Company.
22. Mostyn	Mostyn	James Thomas Cookney.
23. Mount Pleasant	Hawarden	Mount Pleasant Company.
24. Nant Mawr	Hawarden	Hancock and Co.
25. Rhyd Galad	Mold	C. R. Fielding.
26. South Mostyn	Mostyn	Eyton and Co.
27. Tryddyn	Mold	Haworth and Thompson.
28. Tryddyn Farm	Mold	Thomas Baker May.

29. Tryddyn Mill	Mold	Tryddyn Mill Company.
30. Tyn Twll	Mold	Tyn Twll Company.

DENBIGHSHIRE.

1. Aber Dervyn	Ponkey, Ruabon	Thomas Williams and Co.
2. Afonetha	Ruabon	Robert Williams, Lawrence Kay, & John Lloyd.
3. Afonetha Gin Pit	Ruabon	John Wright.
4. Black Park	Chirk	Thomas Edward Ward.
5. Brymbo	Wrexham	Brymbo Coal and Iron Company.
6. Bryn Malley	Wrexham	Bryn Malley Colliery Company.
7. Bryn yr Owen	Ruabon	John Taylor and Son.
8. Christionydd	Ruabon	Thomas Edward Ward.
9. Christionydd	Ruabon	Edward Morris.
10. Coed Poeth	Wrexham	John Burton.
11. Coed Poeth	Wrexham	Jonathan Jones and Co.
12. Dolydd	Vale of Llangollen, Ruabon	Dolydd Company.
13. Frood	Wrexham	Johnson and Edwards.
14. Gardden	Ruabon	George Walmsley.
15. Groes	Ruabon	Jonathan Davis and Co.

DENBIGHSHIRE.—*Continued.*

NAME OF COLLIERY.	WHERE SITUATE.	OWNER'S NAME.
16. Mill	Pentre Christionydd, Ruabon	R. C. M. Wright.
17. Pentre Fawr	Wrexham	Daniel Owens
18. Pentre Bychan	Ruabon	Gomar Roberts and Co.
19. Plasissa	Ruabon	Samuel Giller.
20. Plaskynaston	Cefn, Ruabon	Thomas Edward Ward.
21. Ruabon	Ruabon	New British Iron Company.
22. Ruabon Coal and Coke Works	Ruabon	Ruabon Coal and Coke Company.
23. South Sea	Wrexham	South Sea Company.
24. Vron	Wrexham	Maurice and Low.
25. Westminster	Wrexham	Westminster Coal Company.
26. Wynn Hall	Ruabon	William Kenrick.

IRON WORKS IN NORTH WALES.

			Blast Furnaces.		In Blast, Jan. 1854.
1.	Brymbo	Ruabon	2	...	2
2.	Coed Talon	Mold	1	...	0
3.	Frood	Wrexham	1	...	0
4.	Leeswood	Mold	2	...	0
5.	New British Iron Company.	Ruabon	3	...	3
6.	Plasissa	Ruabon	1	...	0
7.	Plaskynaston	Ruabon	1	...	0
8.	Ponkey (Old)	Ruabon	1	...	0
			12		5

Mr. Samuel Salt, the head of the merchandise department of the North-Eastern Division of the London and North-Western Railway, a member of this society and a gentleman well known for his valuable statistical publications on commerce, has been so kind as to furnish to the society a return of all the coal brought into Manchester by all conveyances, viz., by road, rail, and water. Mr. Salt obtained his information himself from various sources with very great care for all the years hereunder mentioned, except those for 1834, 1836, and 1840, which were from other sources.

	TONS.
1834	737,008
1836	913,991
1840	1,034,090
1847	954,719
1848	1,010,383
1849	1,129,171
1850	1,120,184
1851	1,241,854
1852	1,436,058
1853	1,221,272

A gentleman engaged in the coal trade estimates the total consumption of coal by Manchester and Salford at 2,000,000 of tons, in round numbers.

V.—*On the Action of the Ferment of Madder on Sugar.*

By Edward Schunck, Ph.D., F.R.S.

[*Read April 4th*, 1854.]

In a paper read before the Royal Society in 1852,* I have given an account of the nature and results of the peculiar process of fermentation which takes place in madder and its watery extracts, when exposed to a moderate degree of temperature. I have shown that during this process the bitter principle of madder, to which I have given the name of *Rubian*, is completely decomposed, giving rise to the formation of a number of substances, of which alizarine, the true colouring matter of madder, is the most remarkable. I have stated that this process is not accompanied by the evolution of gas or any of the usual signs of fermentation, that the access of atmospheric air is not necessary for its completion, and that the rapidity with which it is effected is remarkable. Lastly, I have given an account of the properties and composition of the ferment itself. I have shown, that as regards the power of effecting the decomposition of rubian, none of the usual fermentative substances, such as yeast, caseine, &c., are capable of supplying its place, with the sole exception of emulsine, which forms an imperfect substitute for it, that its composition differs in a marked manner from that of the other bodies of the same class in containing a much smaller proportion of nitrogen, and that, in short, it must be considered as

* Philosophical Transactions for 1853. Part I.

a substance altogether *sui generis*. I have given it the name of *Erythrozym*.

In the paper just mentioned I have stated, that "if this substance be mixed with water, and the mixture be allowed to stand for a length of time in a warm place, signs of a more active process of fermentation begin to show themselves, especially in summer weather; bubbles of gas are given off, and a peculiar smell is emitted, which, though disagreeable, cannot exactly be called putrid. During this process, which is evidently one of putrefaction in the stricter sense, the erythrozym loses its sliminess, and is converted into a red flocculent mass, which may easily be separated by filtration from the liquid. The latter is clear, colourless, and quite neutral. After erythrozym has passed through this second stage of decomposition, its power of decomposing rubian is found to have lost much of its intensity. It is during the first period of its decomposition, when no apparent change is taking place, that this power is most energetically exerted. During the second, or more strictly putrefactive stage, it acquires, however, the property of decomposing sugar. If erythrozym be mixed with a solution of cane sugar, and the mixture be allowed to stand for a considerable time until gas begins to be disengaged, the solution acquires by degrees a decided acid reaction." The great interest attaching to bodies of this class induced me to examine this action of the ferment on sugar more minutely, and I have now the honour of laying the results of my investigation before the Society.

In order to obtain the ferment for the purpose of decomposing sugar, it is not necessary to prepare it by precipitation with alcohol, as I recommended in my paper on Rubian, nor to pay much attention to its complete purification. I found that the following method of preparation yielded a product perfectly well adapted for the purpose. A quantity of madder (French being the kind employed) having been placed on

a calico strainer, water heated to about 100° F. is poured on it in the proportion of about four quarts of water to every pound of madder. To the dark reddish-brown liquid there is now added a small quantity of muriatic acid. This produces a brown flocculent precipitate, which is allowed to settle, and after the liquid has been decanted, it is washed with a quantity of fresh water, the process being repeated until the excess of acid has been removed, after which the precipitate is collected on a calico strainer. After the water has run off, there is left on the strainer a thick brown pulp. This pulp contains, besides erythrozym, small quantities of pectic acid, colouring matter &c., but these impurities are of no material consequence as regards the process of fermentation. It differs from the erythrozym prepared by precipitation with alcohol in containing no lime or other base, the latter having been removed by the acid used for precipitation. In my experiments, however, I always added a certain proportion of lime water to the solutions to be fermented, as I found that the fermentation was much promoted by this addition.

The bulk of my experiments was made with cane sugar, but I have also subjected grape and milk sugar to the same process of decomposition. In operating on cane sugar I proceeded in the following manner. The sugar having been dissolved in water, I added to the solution for every pound of sugar taken about four quarts of the brown pulp, prepared as just described, and a sufficient quantity of lime water to change the colour of the ferment from brown to dark purple, and to cause a slight alkaline reaction in the liquid. The whole having been well mixed, was left to itself. The vessels which I employed for conducting the operation in, were large earthenware mugs. In warm summer weather, provided the quantity of materials taken was not too small, the fermentation generally commenced on the succeeding day. A copious disengagement of gas took place, and continued for a number of days. The bubbles of gas, in rising, formed,

together with particles of ferment carried up by them, a thick scum on the surface of the liquid, resembling the froth on the surface of fermenting beer. As far as the evolution of gas, however, was concerned, the action did not seem to be quite as energetic as what would have been produced by the action of ordinary yeast on sugar. During this stage of the fermentation, a slight vinous odour might be perceived near the surface of the liquor. After a few days the liquid began to acquire a decided acid reaction, which was first indicated by the colour of the ferment changing from purple to brown. Very soon litmus paper began to be strongly reddened by it. After some time the disengagement of gas ceased, and the particles of ferment all sank to the bottom, leaving a clear, yellowish supernatant liquid. The latter, however, on standing exposed to the atmosphere, seemed constantly to acquire more and more acid properties; and after several weeks' exposure, it was generally found to have a strongly acid taste and smell like that of sour beer. I have generally allowed the mixture to stand for several months, usually from summer to winter, as I imagined that long standing promoted the formation of one of the acid products, whose properties I shall presently describe. Nevertheless, during this lapse of time little or no mould was formed on the surface of the liquor, no decidedly putrid smell was emitted, nor did the mass ever seem to be particularly attractive to insects, or to breed worms or larvæ, at least none that were visible to the naked eye.

Now the products of this process of fermentation are of three kinds: gaseous, liquid, and solid. I shall describe them in the order mentioned. For the purpose of examining the gaseous products, 2 lbs. of cane sugar were dissolved in water, and the usual quantities of ferment and lime-water were added. After two days the mixture was found to be in a state of active fermentation. A portion of it was then introduced into a capacious bottle, leaving a small space at the

top, which was filled up with oil in order to prevent frothing. The gas was allowed to escape through a bent tube carried through the cork. In order to expel all the air which might be left in the apparatus, the disengagement of gas was allowed to proceed for a whole day before any of it was collected for examination. Six cubic inches were then collected in a graduated tube over mercury. Caustic soda was then introduced into the tube in order to absorb the carbonic acid. The residual gas consisted almost entirely of hydrogen. Its amount was determined by means of oxygen and spongy platinum. After making the necessary corrections for temperature and pressure, the 6 cubic inches of mixed gas were found to consist of 4.90 carbonic acid, 0.96 hydrogen, and 0.14 atmospheric air or nitrogen. The day afterwards I collected 5.16 cubic inches of gas, and found it to contain 4.41 carbonic acid and 0.75 hydrogen. Three days later again, 5.77 cubic inches of gas were collected, and found to be composed of 4.86 carbonic acid, 0.76 hydrogen, and 0.15 atmospheric air or nitrogen. According to these three determinations, the proportion of hydrogen to carbonic acid was respectively as 1 : 5.10, 1 : 5.88, and 1 : 6.39. It appears, therefore, that the carbonic acid increased in quantity relatively to the hydrogen, as the fermentation proceeded.

The liquid products of the fermentation were examined in the following manner. A solution of 4 lbs. of cane sugar was mixed with 19 quarts of brown pulp, to which lime water had been previously added in the usual proportion. The mixture was allowed to ferment for about two weeks, during which time much gas was disengaged. The liquid, which had acquired an acid reaction, was then strained through calico, after which it measured 36 quarts. These 36 quarts were introduced into a still, and distilled until 8 quarts had passed over. By a second distillation I obtained 2 quarts, and by a third distillation 12 fl. oz. of a liquid, which was inflammable, alcoholic in taste and smell, devoid

of acid reaction, and having a specific gravity of 0.973. Assuming it to consist entirely of alcohol and water, of which there is little doubt, the 12 fl. oz. of this specific gravity would correspond to 1072½ grs. of absolute alcohol. The only peculiarity which I noticed about it as distinguishing it from ordinary spirits of wine from other sources, was that it appeared to be filled with a quantity of small, white, glistening, micaceous scales, which gave the liquid when agitated the appearance of being traversed with silky bands. On filtering, these scales remained on the filter, but their quantity was so insignificant that they could not again be separated from the paper.

The liquid remaining in the retort after the second distillation was added to that remaining after the third distillation, and evaporated together with an excess of carbonate of soda until the bulk was very much diminished. The liquid was then supersaturated with sulphuric acid, and distilled. The distillate was colourless, but had a strong acid taste and reaction. It was neutralized with carbonate of soda, and then gave on evaporation a crystalline mass, which was white with a brownish tinge. This mass when treated with boiling dilute sulphuric acid, evolved a pungent smell like that of acetic or formic acid. Its watery solution gave reactions, similar to those of formiate of soda. It gave, for instance, with nitrate of silver a white crystalline precipitate, which soon became black when left to stand, but immediately on boiling the liquid; with protonitrate of mercury, a white crystalline precipitate, which on standing was slowly reduced to grey metallic mercury; and with corrosive sublimate it produced, on boiling, a copious deposit of white crystalline scales (calomel). But on adding acetate of lead, evaporating to dryness, and treating the residue with alcohol, no crystals of formiate of lead were left undissolved. I therefore concluded that the salt consisted for the most part of acetate of soda, contaminated with some impurity, which obscured the reac-

tions proper to acetic acid. Whether the acetic acid thus obtained is a product of the direct action of the ferment on sugar, or whether it is formed indirectly from the oxidation of the alcohol produced in the first instance, is uncertain. The greater part of the acid found in the fermented liquor after exposure for some time, in quantities so considerable as to impart to the liquid a strong acid taste and smell, is without doubt derived from the latter source.

The last product of this process of fermentation which I shall have to mention, is solid, and though the most interesting of them all, is formed in such small quantities as to render its identification difficult. In order to obtain an appreciable quantity of it, it is necessary to employ several pounds of sugar. The solution of sugar being mixed with ferment and lime water in the proportions stated above, the mixture is allowed to ferment, and to stand for several weeks at least, after the disengagement of gas has ceased. The liquid is then strained through calico, and the ferment which remains on the calico in an apparently unchanged state, is washed with water until the percolating liquid is no longer acid. The liquid is then rendered alkaline by means of lime water, and again strained, in order to separate a small quantity of flocks thrown down by the lime. Sugar of lead is now added to it, which produces a dirty pinkish-white precipitate. This is collected on a filter, washed with water, and decomposed with sulphuretted hydrogen. The acid liquid filtered from the sulphuret of lead is usually dark brown or black, from sulphuret of lead in a state of suspension. During evaporation, however, it deposits this sulphuret of lead, and after being again filtered is clear, though still very brown. After being evaporated almost to a syrup, milk of lime is added to it, and the mixture is boiled. The lime removes a quantity of phosphoric acid, which is probably derived from undecomposed phosphates contained in the ferment, and also a great part of the brown colouring matter.

Through the filtered liquid, which is much lighter in colour than before, I now pass a stream of carbonic acid gas, until the excess of lime is completely neutralized, after which it is evaporated almost to dryness. The carbonate of lime which is deposited during evaporation is separated by filtration, and the liquid is evaporated with the addition of an excess of muriatic acid, until it leaves a thick dark brown syrup. In this syrup there is formed, after cooling and standing, a mass of crystals. These crystals must now be strongly pressed between folds of blotting paper, until the whole of the syrupy mother liquor containing chloride of calcium and other impurities has been absorbed. The crystalline mass left on the paper, which has a light brown colour, is now treated with boiling alcohol, which leaves undissolved a quantity of sulphate of lime. The alcohol, after filtration, is evaporated to dryness, the residue is re-dissolved in boiling water, and the solution is decolourized with animal charcoal. The solution now leaves on evaporation to dryness a colourless crystalline mass, consisting partly of needles and plates, partly of crystalline crusts. Now this crystalline mass is found to possess the properties of an acid in a very marked manner. Its taste is at first strongly acid, but this is immediately followed by a nauseous, somewhat metallic after-taste. Its solutions redden litmus paper strongly. When heated on platinum foil it melts and burns with a very pale flame, leaving a slight carbonaceous residue. When heated in a glass tube it melts, and crystallizes again on cooling. When further heated it is volatilized, yielding fumes which strongly affect the nostrils and throat, produce a choking sensation, and excite violent coughing. The fumes condense on the colder parts of the tube, partly in the shape of needles, partly as a white, crystalline, radiated mass. Very little carbonaceous residue is left, and even this is probably due to impurities, so that the acid may be considered as completely volatile. The watery solution of the acid gives the following reactions.

On adding lime water until the solution is alkaline, no precipitate is produced. On boiling a very slight flocculent deposit is formed. The filtered solution leaves on evaporation a crystalline mass, which dissolves again for the most part in boiling water, leaving undissolved only a small quantity of carbonate of lime. The filtered solution is neutral to test paper, and, on being again evaporated, leaves a quantity of long white needles, consisting, without doubt, of the lime salt. The taste of these crystals is nauseous. When heated in a glass tube they become black and give fumes, but no crystalline sublimate; the residue dissolves in acids, with effervescence, leaving some carbon undissolved. On adding baryta water to the watery solution of the acid, there is formed immediately a white flocculent precipitate, which is soluble in muriatic acid, and is again formed on neutralizing the acid with ammonia. Perchloride of iron gives no precipitate in the watery solution of the acid, but in the solution of the lime salt it gives a copious light brown precipitate. Acetate of lead gives immediately a slight flocculent precipitate. If the liquid be filtered from this precipitate, and be allowed to stand for a day or two, there are formed on the bottom and sides of the vessel a number of lustrous, well-developed crystals of a rhombohedral form. The liquid yields on evaporation, no more crystals, but only a syrup of acetate of lead. Nitrate of silver produces no precipitate in the watery solution of the acid, but on the addition of ammonia, a copious white precipitate is formed, which, on standing, becomes somewhat crystalline. This precipitate is soluble in nitric acid and ammonia. Acetate of copper gives almost immediately a blue crystalline precipitate, which increases in quantity on standing. It is not soluble in boiling water, but dissolves in acetic acid. These reactions coincide in every, even the minutest, particular with those of succinic acid, a fact of which I have convinced myself by a comparative examination

of succinic acid derived from the usual source. The analysis of the acid, and its silver salt, gave results which leave no doubt of its perfect identity with succinic acid.

0.2795 grm. of the crystallized acid, dried at 212° F. and burnt with chromate of lead, gave 0.4175 grm. carbonic acid and 0.1480 grm. water.

These numbers correspond to the following composition:—

			Succinic Acid $C_4H_6O_4$ contains
Carbon	40.73	.....	40.67
Hydrogen	5.88	.....	5.08
Oxygen	53.39	.....	54.25
	100.00	.....	100.00

The silver salt was prepared by dissolving the acid in water, then adding nitrate of silver, and neutralizing with ammonia. The white granular precipitate which fell was collected on a filter, washed with water, and dried in vacuo, until its weight remained uniform; after which it was submitted to analysis.

0.6275 grm. of the salt burnt with chromate of lead gave 0.3400 grm. carbonic acid and 0.0890 grm. water.

0.2850 grm. gave 0.2410 grm. chloride of silver.

These numbers lead to the following composition:—

			Succinate of silver $C_4\ H_2\ O_3 + Ag\ O$ contains
Carbon	14.77	.....	14.46
Hydrogen	1.57	.....	1.20
Oxygen	15.29	.....	14.46
Oxide of silver	68.37	.....	69.88
	100.00	.....	100.00

It will be seen that the composition, as determined by these analyses, is only an approximation to what it should be by calculation. Both analyses show an excess of carbon, and a still greater of hydrogen, while the amount of oxide of silver is deficient. Such discrepancies are almost unavoidable in the analysis of substances, which like this are obtained in such extremely minute quantities, and which it is consequently

almost impossible to bring into a state of perfect purity without losing nearly the whole quantity obtained.* Were the atomic weight of the acid yielded by this process much higher, there might still be doubts concerning its composition and identity; but as the amount of discrepancy between the calculated composition and that found by experiment does not, in the case of any one of the constituents of either the acid or the silver salt, correspond to more than half an equivalent,† and as the reactions of the acid agree so entirely with those characteristic of succinic acid, I think there can be no room for any uncertainty.

Besides this acid, I have not been able to discover any other solid product of decomposition resulting from this process. Through the liquid filtered from the lead precipitate containing the succinic acid I have passed sulphuretted hydrogen until all the lead was precipitated, and then filtered and evaporated. A sweet brown syrup was left, consisting apparently of undecomposed sugar, which, though allowed to stand for a length of time, yielded no trace of anything crystalline. Part of this syrup being redissolved in water, and the solution being again evaporated with the addition of acetate of zinc, no crystals were formed, and the residue left after evaporation was completely soluble in alcohol—a proof of the absence of lactic acid.

The products resulting from this process of decomposition are therefore the following:—carbonic acid, hydrogen, alcohol, acetic acid, and succinic acid. Of these the last-named is the

* In order to procure the acid used for the two analyses given above, I was obliged to subject about 26 lbs. of sugar to fermentation. The time and labour required to obtain a sufficient quantity of ferment for the purpose (about 100 quarts) are very great.

† In the analysis of the acid given above the quantities of C, H and O are to one another as 24 : 3.4 : 31.4, or expressed in numbers of equivalents as 4C : 3.4H : 3.9O The amount of the different constituents found in the silver salt are to one another as 24 : 2.5 : 24.8 : 111, or expressed in equivalents as 4C : 2.5H : 3.1O : 0.95 Ag O.

most remarkable; and its formation, though it has been observed in other processes of fermentation, is still so uncommon as to call for some further observation.

I have discovered that on allowing grape sugar or sugar of milk to ferment together with erythrozym and lime water in the same way as cane sugar, succinic acid is also formed. Indeed from sugar of milk I obtained in one experiment more than three times as much of this acid as was ever afforded under the most favourable circumstances by the same quantity of cane sugar. From 1 lb. of cane sugar I never obtained more than $3\frac{1}{2}$ grs. of acid. In the experiment just referred to I obtained from $\frac{1}{2}$ lb. of sugar of milk nearly 6 grs. of acid. The quantities formed, even under apparently the same circumstances, were, however, very variable. Large quantities of cane sugar sometimes yielded only traces of acid, while smaller quantities gave proportionally a large amount. It is during the later stages of the fermentation, I imagine, that the acid is chiefly formed. At least, I have always found that its amount was greater after the fermenting liquid had stood for several weeks or months than during the first period of the fermentation, when the disengagement of gas was most active. Whether the access of atmospheric air is necessary for, or promotes the formation of, the succinic acid, I am unable to say. I may mention, that the phenomena attending the fermentation of grape sugar and sugar of milk are apparently the same as when cane sugar is employed.

In order to be quite sure that the formation of the succinic acid and the other products was due to the action of the ferment on the sugar, and not to the decomposition of the ferment itself, I have repeatedly allowed mixtures of the ferment and lime water, without the addition of sugar, to stand exposed to a warm temperature and under the same conditions under which the fermentation was usually conducted. In this case little or no gas was disengaged,

the liquid never became acid, and the ferment remained purple and sank to the bottom of the vessel. After standing for several weeks, the filtered liquid gave with sugar of lead a pinkish-white precipitate, which seemed, however, to consist principally of carbonate of lead, as on treating a small quantity of it with nitric acid it dissolved with effervescence. This precipitate being decomposed with sulphuretted hydrogen, and the liquid being treated in exactly the same manner as that resulting from the crude succinate of lead in the other experiments, a syrup was obtained, which yielded however not a trace of crystalline sublimate when heated in a tube. The formation of the succinic acid, as well as of the alcohol and the gases, is therefore clearly due to the decomposition of the sugar induced by the action of the ferment.

Since madder itself contains a considerable quantity of sugar ready formed, and an additional quantity is always produced by the decomposition of rubian, it was natural to suppose that watery extracts of madder might be found to contain succinic acid. For the purpose of ascertaining whether this was the case, I took some of the brown syrup which had been obtained by extracting French madder with boiling water, precipitating the colouring matter &c., with oxalic acid, neutralizing the excess of acid with carbonate of lime, and evaporating the filtered liquid, which had been standing in the state of syrup for several years. A quantity of this syrup having been mixed with water, I added to it acetate of lead, which produced a dark brown precipitate. This precipitate being treated in precisely the same manner as the lead precipitate thrown down by sugar of lead from the solutions of sugar fermented with erythrozym, yielded a small quantity of a white crystallized acid, which, when heated in a tube, was completely volatilized, giving a beautiful crystalline sublimate, exactly resembling that produced by succinic acid. It is therefore very probable that succinic acid is either contained as such in madder, or is formed during or after the

process of extraction by the action of the ferment on the sugar contained in the extract.

A few years ago the only known sources of succinic acid were amber, turpentine, and some species of brown coal and retinasphalt. Latterly it has been discovered in several plants, such as the *Lactuca sativa* and *virosa*,* and the *Artemisia Absinthium*,† and it has been detected in the liquid extracted from cysts containing echinococci from the human liver.‡ It has moreover been produced artificially by the action of nitric acid on different kinds of fat and fatty acids, such as tallow, wax, spermaceti, and stearic and margaric acids,‖ and its formation during the fermentation of asparagine, malic acid and their compounds is one of the most interesting facts of organic chemistry. As far as I know, however, its direct formation from sugar has not hitherto been observed, and I consider this as the most important fact revealed by this investigation. In future, should its presence be detected in any part of the vegetable or animal organism, its origin need no longer be a subject for doubtful speculation, as it is now known to be a product of the decomposition of sugar, whether it be cane sugar, grape sugar, or sugar of milk.§

* Köhnke, Brandes Archiv, 2 ser., XXXIX. 153.

† Zwenger, Annalen der Pharmacie, XLVIII. 122.

‡ Heintz, Poggendorff's Annalen, LXXX. 114.

‖ Bromeis, Stlamer, Radcliffe, Ronalds, Annalen der Pharmacie, XXXV. 90; XLIII. 346, 349, 356.

§ The only indication which I can find of the formation of succinic acid from sugar having previously been observed, is a statement of Beissenhirtz (Berlinisches Jahrbuch der Pharmacie, anno 1818, p. 158), who allowed a mixture of honey, bread, *siliqua dulcis* (the fruit of the *ceratonia siliqua*), vinegar, spirits of wine, and water, to ferment, neutralized the acid with lime, and then subjected the solution of the lime salt to distillation, together with oxide of manganese and sulphuric acid, when he obtained first a distillate of acetic acid, and afterwards a sublimate of succinic acid. Here the *siliqua dulcis* probably yielded only the ferment, since John could discover in it no succinic acid, ready formed, and the honey the sugar acted on. Plümacher repeated this experiment, but without success. Piria discovered that asparagine is formed during the germination of the seeds of various leguminosæ, such as peas, beans, and

I shall venture, in conclusion, to offer a few remarks on the general nature of the process of fermentation here described, and its relation to other processes of the same kind previously known.

The highly interesting and peculiar class of bodies called ferments, comprises substances which are all of a very complex nature, and are at the same time not characterized by any marked peculiarities in their appearance, form, or general properties. It is chiefly by their action on other bodies, by the different species of decomposition which they induce in the latter, and by the nature of the products thereby formed, that we are enabled to distinguish the ferments from one another, and arrange them in different classes. Now the effects or species of decomposition produced by ferments are of two kinds: general and specific. The general effects are those produced by all ferments, without distinction, or are common to several classes of ferments. The specific effects are those peculiar to each ferment alone. The general effects are again of different kinds, some being produced during the first stages of the fermentation, others when the process has somewhat advanced, others when it approaches a conclusion—these different effects corresponding to different stages of decomposition in the ferment itself. I think I am correct in saying, that there are only two well-known instances of specific effects due to ferments. The one is the decomposition of amygdaline (and salicine?) by means of emulsine, the ferment contained in almonds; the other the decomposition of rubian by means of erythrozym. No known ferment,

vetches, and that the asparagine, by fermentation, yields succinic acid. Dessaignes could not discover what body contained in the seeds it is, which leads to the formation of asparagine, but he found that pea flour, when allowed to ferment with caseine, produced considerable quantities of succinic acid. It is now evident that this acid may have been formed directly from the starch of the pea flour, though it is possible (and it would be a fact of uncommon interest if it were discovered to be the case), that the latter passes through the intermediate stage of asparagine.

with the exception of emulsine, has any effect whatever on amygdaline,* and none of the usual ferments, such as yeast, decomposing caseine, albumen, gelatine, or even emulsine, are capable of supplying the place of erythrozym, as far as regards the decomposition of rubian.† These specific effects of emulsine and erythrozym are more characteristic of these bodies than any other property whatever, and serve to distinguish them from one another and from other ferments with more accuracy than any difference in composition, however great. On the other hand, the decomposition of sugar into alcohol and carbonic acid is an effect common to all known ferments. All so-called proteine compounds, such as albumen, caseine, animal membranes &c., when they enter into decomposition, acquire the properties of ferments. When all other circumstances are alike, the processes of decomposition to which these compounds, when acting as ferments, give rise in other bodies, are precisely the same. The species of decomposition varies only according to the particular stage of decomposition of the ferment itself. During the first stage of decomposition they convert starch into sugar; during the second stage they change sugar into alcohol and carbonic acid, bile into cholalic acid, taurine, and other products, and tannic into gallic acid; when they have entered on the third stage of decomposition, they effect the conversion of sugar into lactic acid, and of lactic acid into butyric acid, carbonic acid, and hydrogen. All these various effects may be produced by emulsine, provided the latter be in the state of

* I have mixed amygdaline and erythrozym, and amygdaline and madder itself, together with water, to the consistence of paste, and allowed the mixtures to stand for days in a warm place, without perceiving any signs of the decomposition of the amygdaline; while a mixture of amygdaline, emulsine, and water, will under the same circumstances, evolve the peculiar smell of oil of bitter almonds in a very short time.

† Emulsine is indeed not entirely without effect on rubian, but the quantity of the latter which it is capable of decomposing, even after a long lapse of time, is extremely insignificant.

decomposition appropriate to their respective production. The alcoholic fermentation of sugar is also effected by erythrozym, as I have shown.*

But it still remains uncertain, and the point is one of considerable interest, whether the formation of succinic acid from sugar is a specific effect due to erythrozym alone, or is shared by the latter in common with other ferments, such as yeast and emulsine. On this point I have no evidence to offer, but must content myself with a few general considerations, leading to the conclusion, that it is not improbable that other ferments will be found capable, under peculiar circumstances, of producing this acid from sugar.

The conversion of sugar into alcohol and carbonic acid, and also that of sugar into butyric acid, carbonic acid, and hydrogen, are well understood processes. In the former case 1 eq. of sugar splits up into 2 eq. of alcohol, and 4 eqs. of carbonic acid.

1 eq. Sugar. Alcohol.

$$C_{12}\ H_{12}\ O_{12} = 2C_4\ H_6\ O_2 + 4\ C\ O_2$$

In the second case, 1 eq. of sugar splits up into 1 eq. of butyric acid, 4 eqs. of carbonic acid, and 4 eqs. of hydrogen.†

1 eq. Sugar. Butyric Acid.

$$C_{12}\ H_{12}\ O_{12} = C_8\ H_8\ O_4 + 4\ C\ O_2 + 4\ H$$

But as regards succinic acid, it is difficult to indicate with positive certainty in what manner it takes its rise from sugar, because, in the fermentation of the latter with erythrozym, it is evident that there are two processes going on side by side, the one being the formation of alcohol, the other that of

* It is possible that butyric acid may also be one of the products of the action of erythrozym on sugar, though it is not probable, as among these products I have not been able to detect lactic acid, which constitutes the intermediate stage between sugar and butyric acid.

† I leave out of consideration the fact that sugar, before being decomposed, in the manner mentioned, is first converted into lactic acid; but this fact is of no consequence as regards the result, since sugar and lactic acid have the same percentary composition.

succinic acid; and it is doubtful whether all the carbonic acid evolved is due to the one process alone or not, and also whether all the acetic acid formed arises from the oxidation of the alcohol, or whether a part of it does not proceed directly from the decomposition of sugar.

That the disengagement of hydrogen in this process stands in some relation to the formation of succinic acid, will admit, I think, of no doubt; but I would not venture to assert that the whole quantity of that gas evolved is due to the process of decomposition by which this acid is formed. Of the possible modes of decomposition by which succinic acid may be formed from sugar, I will indicate a few. One equiv. of sugar may split up into 3 eqs. of succinic acid and 3 eqs. of hydrogen; or with the elements of 8 eqs. of water into 1 eq. of succinic acid, 8 eqs. of carbonic acid, and 17 eqs. of hydrogen; or into 1 eq. of succinic acid, 2 eqs. of acetic acid, and 1 eq. of hydrogen; or into 2 eqs. of succinic acid, 1 eq. of acetic acid, and 2 eqs. of hydrogen; or together with the elements of 2 eqs. of water into 2 eqs. of succinic acid, $\frac{1}{2}$ eq. of acetic acid, 2 eqs. of carbonic acid, and 8 eqs. of hydrogen, as the following equations will show:—

Succinic Acid.

$$C_{12} H_{12} O_{12} = 3\,C_4 H_3 O_4 + 3\,H$$

$$C_{12} H_{12} O_{12} + 8\,H O = C_4 H_3 O_4 + 8\,C O_2 + 17\,H$$

Acetic Acid.

$$C_{12} H_{12} O_{12} = C_4 H_3 O_4 + 2\,C_4 H_4 O_4 + H$$

$$C_{12} H_{12} O_{12} = 2\,C_4 H_3 O_4 + C_4 H_4 O_4 + 2\,H$$

$$C_{12} H_{12} O_{12} + 2\,H O = 2\,C_4 H_3 O_4 + \tfrac{1}{2}\,C_4 H_4 O_4 + 2\,C O_2 + 6\,H$$

Of these different modes of decomposition, I consider the last as the most probable. At all events I prefer for the present considering it as the true one, since it shows the possibility of all the products of decomposition, except the alcohol, being formed from one equivalent of sugar. It corresponds with the mode of decomposition according to which Liebig supposes malic acid to split up into succinic, acetic,

and carbonic acids.* Taking this for granted, the following relations will be found to subsist between the products formed in the alcoholic, butyric acid, and succinic acid fermentations of sugar. In all these processes, 1 eq. of sugar splits up into one or more organic bodies, and one or more inorganic ones. The quantities of carbonic acid formed in the three processes are to one another respectively as 2 : 2 : 1, the quantities of hydrogen as 0 : 2 : 3. In the organic products formed in the three processes (adding together the elements of the succinic and acetic acids of the last process), the numbers of equivalents of carbon, hydrogen, and oxygen, are to one another as follows:—in the products of the alcoholic fermentation the C : H as 2 : 3; in those of the butyric acid fermentation, as 2 : 2; in those of the succinic acid fermentation, as 5 : 4; while the numbers of equivalents of oxygen and hydrogen are to one another respectively as 1 : 3, 1 : 2, and 5 : 4. Passing along the series from the products of the alcoholic to those of the succinic acid fermentation, the number of equivalents of hydrogen in the organic substances is found to be constantly on the decrease, as compared with that of the equivalents of carbon and oxygen, while the amount of hydrogen set at liberty increases in the same ratio.

That time may form an important element in all processes of fermentation, and that the degree of rapidity with which such processes are completed may have a considerable influence on the nature of the products formed, has, I think, been rendered evident by my experiments on the fermentation of rubian. Indeed I would go further, and assert that the difference in the effect produced by the same ferment, under different circumstances, is a direct consequence of the greater or less degree of rapidity in the change which its elements may be undergoing, and of the consequent more or less rapid motion communicated to the elements of other bodies. The very simplest experiments in organic chemistry are sufficient

* Annalen der Pharmacie, LXX. 363.

to prove that a body subjected to a process of rapid decomposition yields very different products to what it does when the same process is slowly conducted.

Now the butyric acid fermentation of sugar differs chiefly from the alcoholic in the length of time which it requires for its completion. The numbers and ratios, which I have here (somewhat hypothetically, perhaps) placed in juxtaposition, seem to indicate that the fermentation by which succinic acid is formed from sugar is characterized by still greater slowness, and that, by sufficiently retarding the action of ordinary ferments on sugar, we may also by means of these succeed in forming succinic acid in saccharine solutions, perhaps even in considerable quantities.

VI.—*On the k-partitions of* N.

By the Rev. Thomas P. Kirkman, A.M., Rector of Croft-with-Southworth.

[*Read January 10th*, 1854.]

Any system of k numbers written in the order of their magnitude, whose sum is N, and of which none is less than a, may be represented thus;

$$(a+x_1)+(a+x_1+x_2)+(a+x_1+x_2+x_3)+ \ . \ . \ . \ . \ . \ . \ . \ .$$
$$+(a+x_1+x_2+ \ . \ . \ . \ +x_k)=\mathrm{N}.$$

where x_1x_2 &c. may be anything positive or zero; for none of these k numbers is less than the preceding one, but exceeds it by any difference which is either positive or nothing. And it is plain that no element x_e can be altered in value, the equation remaining true, without giving rise to a new system of k numbers whose sum is N, none of them being less than a.

From this equation, written under the form,

$$k\cdot\overline{a+x_1}+\overline{k-1}\cdot x_2+\overline{k-2}\cdot x_3+ \ . \ . \ . \ . +3x_{k-2}+2x_{k-1}+x_k=\mathrm{N}, \quad \text{(A)}$$

many interesting properties can be deduced. Its solutions, in null or positive values of x, x_2 &c., are in number equal to that of the different ways in which N can be broken into k whole numbers none less than a. I shall confine myself here to an important deduction from A. Writing it thus,

$$\overline{k-1}\cdot\overline{a+x_2}+\overline{k-2}\cdot x_3+\overline{k-3}\cdot x_4+ \ . \ . \ . \ . \ .+2\cdot x_{k-1}+x_k$$
$$=\mathrm{N}-a-kx_1; \quad \text{(B)}$$

we see that the number of solutions is the same in B as in A;

and that if x_1 be confined to any value f, which it can receive in (A), the number of solutions of (B) is that of the (k—1)-partitions, as they are called, of N—a—kf. Now x_1 may have any value from zero up to the greatest integer in (N—a) : k. Hence it appears that the k-partitions of N, none of which contains a part less than a, are equal in number to the (k—1)-partitions of N—a+the (k—1)-partitions of N—k—a+the k—1-partitions of N—2k—a, &c., as far as k can be continually subtracted to leave a remainder not negative; no part, in any of these (k—1)-partitions, being less than a. Take a=1, and let ${}_kP_x$ denote the number of k-partitions of x; then the theorem just proved is expressed thus, if

$$x=ke+c, \quad x-k=k(e-1)+c, \quad c>0, \quad <k+1,$$

$$\left.\begin{aligned} {}_kP_x &= {}_{k-1}P_{x-1}+{}_{k-1}P_{x-1-k}+{}_{k-1}P_{x-1-2k}+\ldots+{}_{k-1}P_{c-1};\\ {}_kP_{x-k} &= \quad {}_{k-1}P_{x-1-k}+{}_{k-1}P_{x-1-2k}+\ldots+{}_{k-1}P_{c-1}; \end{aligned}\right\} \text{(C)}$$

whence follows

$${}_kP_x-{}_kP_{x-k}={}_{k-1}P_{x-1} \qquad \text{(D)}$$

From this equation of differences ${}_kP_x$ can be found. It is easily seen that

$${}_2P_x=\tfrac{1}{2}(x-{}^*2_{x-1}), \qquad \text{(E)}$$

Where ${}^*2_{x-1}$ is that well known function of the square roots of unity which is = 1 for x odd, and = 0 for x even. To the reader who is not familiar with these *circulators*, as they are called, it is sufficient for our purpose here to *define*, that $\pm a\cdot{}^*s_e$ in this paper is to be read as $\pm a$, when the quotient $e:s$ is a positive integer, and as ± 0, when $e:s$ is either fractional or negative; where it is to be remembered that $0:s$, e being zero, is always counted whole and positive. The last equation affirms that the bi-partitions of x are $\frac{1}{2}x$ in number when x is even, and $\frac{1}{2}(x-1)$, when x is odd, the truth of which needs no demonstration. By equations C and D, if $x=3e+c$, c being >0, = 1, 2, or 3,

$$ {}_3P_x = {}_2P_{x-1} + {}_2P_{x-4} + {}_2P_{x-7} + \ldots + {}_2P_{c-1}, \qquad c. $$

$$ {}_3P_{x-3} = \quad {}_2P_{x-4} + {}_2P_{x-7} + \ldots + {}_2P_{c-1}, \qquad c'. $$

$$ {}_3P_x - {}_3P_{x-3} = {}_2P_{x-1}. \qquad d. $$

The function ${}_3P_x$ can be found from (c) by summing $\Sigma_2 P_{x+2}$ which is by (E),

$$ = \Sigma \frac{x+2}{2} - \tfrac{1}{2}\Sigma^* 2_{x+1}, $$

$$ = \tfrac{1}{2}\Sigma(3e+c+2) - \tfrac{1}{2}\Sigma^* 2_{x+1}; $$

or to prevent any ambiguity arising from the three values of c,

$$ \tfrac{1}{2}\Sigma^* 3_{x-c}\Sigma(3e+c+2) - \tfrac{1}{2}\Sigma^* 2_{x+1}; $$

between the proper limits. This labour, however, we can easily avoid; but it is useful to observe that we are to expect in our results terms multiplied by $^*3_{x-1}$, $^*3_{x-2}$, and $^*3_x$, as well as by $^*2_x$ and $^*2_{x+1}$.

Every term ${}_2P_{x-f}$ of equation (c) on the right side has an ordinary algebraic portion, viz. $\frac{1}{2}(x-f)$. If we sum all these in both (c) and (c'), and denote those sums by $({}_3P_x)$ and $({}_3P_{x-3})$, we shall, if we subtract the latter of these from the former, have remaining the algebraic portion of ${}_2P_{x-1}$, which we may denote by $[{}_2P_{x-1}]$; that is, we obtain

$$ ({}_3P_x) - ({}_3P_{x-3}) = [{}_2P_{x-1}] = \tfrac{1}{2}(x-1). \qquad d'. $$

As not more than one power of x can disappear by this subtraction, and the first only is found in the remainder, we know that

$$ \begin{aligned} ({}_3P_x) &= Ax^2 + Bx + C, \\ -({}_3P_{x-3}) &= -Ax^2 + 6Ax - 9A \\ &\quad - Bx + 3B \\ &\quad - C; \end{aligned} $$

whose sum is

$$ +\tfrac{1}{2}x \quad -\tfrac{1}{2}. $$

Hence follows

$$ A = \frac{1}{12}, \qquad B = \frac{1}{12}, $$

$$ ({}_3P_x) = \frac{x^2}{12} + \frac{x}{12} + C. $$

When $x-3\overline{\equiv}0$, ${}_3P_{x-3}$ in equation (c') has no terms whatever, and $[d']$ becomes, since $x=0\cdot 3+c$,

$$({}_3P_c)=[{}_2P_c]$$

$$\frac{c^2+c}{12}+C=\frac{c-1}{2},$$

$$C=-\frac{c^2-5c+6}{12}=-\frac{2\cdot{}^*3_{x-1}}{12};$$

for it vanishes for $c=2$, or $c=3$, and when $c=1$, it is $-\frac{2}{12}$. The portion $({}_3P_x)$ of ${}_3P_x$ is thus proved to be

$$({}_3P_x)=\frac{x^2+x-2\cdot{}^*3_{x-1}}{12}.$$

To find the rest of ${}_3P_x$, which for anything yet shown, may also contain an ordinary algebraic portion, we have to sum the $(e+1)$ terms

$$-\tfrac{1}{2}({}^*2_{x-2}+{}^*2_{x-5}+\cdots+{}^*2_{c+1}+{}^*2_{c-2})$$

If $e+1=2h$, or $x=6h+c-3$,
this is

$$-\frac{h}{2}\cdot{}^*2_x-\frac{h}{2}{}^*2_{x-1}=-\frac{h}{2}=-\frac{x+3-c}{12};$$

for ${}^*2_{c-2}=1$ for x odd, c being then $=2$, and ${}^*2_{c+1}$ even, c being either $=1$ or 3: and the equation just written is true, whether x be odd or even, as ${}^*2_x+{}^*2_{x-1}=1$, whatever be the integer x.

If $e=2h'$, or $x=6h'+c$,
the above sum is

$$-\tfrac{1}{2}h'{}^*2_x-\tfrac{1}{2}h'{}^*2_{x-1}-\tfrac{1}{2}{}^*2_{c-2}$$

$$=-\frac{x-c}{12}-\frac{6}{12}{}^*2_{c-2}.$$

The sought remainder of ${}_3P_x$ is therefore

$$-{}^*2_{e-1}\cdot\tfrac{1}{12}(x+3-c)-{}^*2_e\cdot\tfrac{1}{12}\cdot(x-c+6\cdot{}^*2_{c-2}),$$

$$=-\frac{x}{12}-{}^*2_{e-1}(3-c)+{}^*2_e(c-6\cdot{}^*2_{c-2}).$$

Consequently, by addition of this to $({}_3P_x)$, $(x=3e+c)$, $(c>0)$,

$${}_3P_x=\tfrac{1}{12}\{x_2-{}^*3_{x-1}\cdot 2-{}^*2_{e-1}\cdot(3-c)+{}^*2_e\cdot(c-6\cdot{}^*2_{c-2})\}.$$

The circulating constant can never be so great as $\frac{1}{2}\cdot 12$, for, to examine the most suspicious-looking case, when $c=2$ and e even, it is only $=2-6=-4$.

It appears, then, that the tri-partitions of x are in number always equal to the integer *nearest* to $\frac{1}{12}x^2$. When $c=3$, and e is odd, $x=6h$; in this case the number ${}_3P_x$ is exactly $\frac{1}{12}x^2$. The expression is easily put into the form following:—

$$ {}_3P_x=\tfrac{1}{12}\{x^2-0\cdot{}^*6_x-{}^*6_{x-1}-4.{}^*6_{x-2}+3.{}^*6_{x-3}-4.{}^*6_{x-4} -{}^*6_{x-5}\}. $$

Using equation (D) to find $({}_4P_x)$ the sum of the ordinary algebraic terms in the equivalent of ${}_4P_x$, we have

$$ \begin{aligned} ({}_4P_x) &= Ax_3+ \quad Bx_2+ \quad Cx+ \quad D \\ -({}_4P_{x-4}) &= -Ax^3+12Ax^2-48Ax+64A \\ &\quad -Bx_2+8Bx-16B \\ &\quad -Cx+ 4C \\ &\quad -D, \end{aligned} $$

whose sum must be the algebraic portion of ${}_3P_{x-1}$, or

$$ [{}_3P_{x-1}]=\tfrac{1}{12}(x-1)^2=\tfrac{1}{12}\cdot(x^2-2x+1). $$

This gives by equating co-efficients

$$ A=\tfrac{1}{144},\ B=\tfrac{1}{72},\ C=-\tfrac{1}{144}. $$

Wherefore

$$ ({}_4P_x)=\frac{x^3}{144}+\frac{3x^2}{144}-\frac{x}{144}+D. $$

If $x=4e+c$, $c>0$, $({}_4P_{c-4})$ has no terms, and

$$ ({}_4P_c)=[{}_3P_{c-1}], \text{ or} $$

$$ \frac{c^3+3c^2-c}{144}+D=\frac{c^2-2c+1}{12}, $$

$$ -D=\frac{c^3-9c^2+23c-12}{144}, $$

$$ =-{}^*4_{x-1}\frac{3}{144}+{}^*4_{x-2}\frac{6}{144}+{}^*4_{x-3}\frac{3}{144}+{}^*4_x0, $$

$$ ({}_4P_x)=\frac{1}{144}\left\{x^3+3x^2-x-{}^*4_{x-1}\cdot 3-{}^*4_{x-2}\cdot 6-{}^*4_{x-3}3\right\}. $$

We have now to sum the circulating constants in the $e+1$ terms

$$ {}_3P_{x-1}+{}_3P_{x-5}+{}_3P_{x-9}+ \ldots +{}_3P_{c-1} $$

which constants are all of the form $k_p \cdot {}^*6_{x-n}$. If $x-1=6m+p$, it is evident that ${}^*6_{x-p-1}$ is the only circulator that can have value. If ${}_3P_x$ contains $k_p \cdot {}^*6_{x-p}$, ${}_3P_{x-1}$ will contain $k_p \cdot {}^*6_{x-p-1}$, ${}_3P_{x-5}$ will contain $k_{p-4} \cdot {}^*6_{x-p-1}$, ${}_3P_{x-9}$ will contain $k_{p-8} \cdot {}^*6_{x-p-1}$; or the $\overline{e+1}$ terms to be summed are

$$ {}^*6_{x-p-1}\,(k_p+k_{p-4}+k_{p-7}+k_{p-12}+ \ldots), $$

the subindices always decreasing by 4, upon the circle

$$ k_0\ k_1\ k_2\ k_3\ k_4\ k_5\ k_0\ k_1 \ldots . $$

Now since every term is identical with the term standing at the twelfth place above it, k_p is identical with k_{p-12}, and the three numbers $k_p+k_{p-4}+k_{p-8}$ will recur. If we put

$$ e+1=3h+i, \text{ or } h=\frac{x-4(i-1)-c}{12}, \ (i<3), $$

$i=0$ gives us for our sought sum exactly

$$ \frac{h}{12}(k_p+k_{p-4}+k_{p-8}); $$

and if $i>0$, we must add to this

$$ \tfrac{1}{12}(k_p+k_{p-4}+ \ldots \text{ to } i \text{ terms}). $$

Now when x is even, p is odd, and *v.v.*, whence, referring to the periodic constant in ${}_3P_x$, we have for the sum of these $e+1$ circulators,

$$ \frac{1}{12}\left(\frac{x}{12}-\frac{4(i-1)+c}{12}\right)\left\{(-1+3-1).{}^*2_x+(-4-4).{}^*2_{x-1}\right\} $$
$$ +\tfrac{1}{12}(k_p+k_{p-4} \ldots \text{ to } i \text{ terms}). $$

Adding this to $({}_4P_x)$ we obtain, putting ${}^*2_x=1-{}^*2_{x-1}$,

$$ {}_4P'_x=\tfrac{1}{144}\Big\{x^3+3x^2-9x.{}^*2_{x-1}-3.{}^*4_{x-1}-6.{}^*4_{x-2}-3.{}^*4_{x-3} $$
$$ -\big(4(i-1)+c\big)\cdot(1-9\cdot{}^*2_{x-1})+12(k_p+k_{p-4} \ldots \text{to } i \text{ terms})\Big\}, $$

where $x=12h+4(i-1)+c=6m+p+1$; $c<5$, and k_p is the co-efficient of ${}^*6_{x-p}$ in ${}_3P_x$, and k_{p-4} the fourth behind it, or

the second above it, in the circle $k_0 k_1 k_2 k_3 k_4 k_5 k_0 k_1 \ldots\ldots$
which is 0,—1,—4,+3,—4,—1,0,—1. . . . .

The greatest value of the constant in ${}_4P_x$ is when $c=2=i$, $p=5$, and $x=12h+6$; then it is

$$-6-6+12(-1+-1)=-36,$$

and it is easy to reduce the value of ${}_4P_x$ to the form

$${}_4P_x=\frac{1}{144}\left\{x^3+3x^2-9x.{}^*2_{x-1}+\Sigma a_p.{}^*12_{x-p}\right\},$$

where $a_0=0$, $a_1=5$, $a_2=-20$, $a_3=-27$, $a_4=32$, $a_5=-11$,
$a_6=-36$, $a_7=5$, $a_8=16$, $a_9=-27$, $a_{10}=-4$, $a_{11}=-11$.

Thus it is evident that ${}_4P_x$ is always the *nearest* integer to the sum of its terms in x.

We proceed next to find ${}_5P_x$, which will have, besides the portion $({}_5P_x)$ obtained by summing ordinary algebraical terms in equation (C), a second portion $({}_5P_x)'$, which has circulating co-efficients of x, or of x, x^2, &c.; besides that which arises from the summation of the constant circulators in ${}_4P_{x-1}$, ${}_4P_{x-6}$, &c. We begin with

$$({}_5P_x)-({}_5P_{x-5})=[{}_4P_{x-1}] \qquad \text{H.}$$

$$\begin{aligned}
{}_5P_x &= Ax^4+Bx^3+Cx^2+Dx+E\\
-{}_5P_{(x-5)} &= -Ax^4+20Ax^3-6\cdot5^2Ax^2+20Ax-5^4A\\
&\quad -Bx^3+15Bx^2-75Bx+5^3B\\
&\quad -Cx^2+10Cx-5^2C\\
&\quad -D+5D\\
&\quad -E
\end{aligned}$$

Whose sum is $\dfrac{(x-1)^3+3(x-1)^2}{12^2}$

$$=\frac{x^3}{12^2}-\frac{3\cdot x}{12^2}+\frac{2}{12^2}.$$

We obtain $A=\dfrac{1}{20\cdot12^2}$, $B=\dfrac{10}{20\cdot12^2}$, $C=\dfrac{19}{20\cdot12^2}$, $D=-\dfrac{22}{20\cdot12^2}$

Wherefore

$$({}_5P_x)=\frac{1}{20\cdot12^2}\left\{x^4+10x^3+19x^2+22x\right\}+E.$$

If $x=5e+c$, $c>0$, we have, reasoning as before,

$({}_5P_e)=[{}_4P_{c-1}]$, whence

$$\frac{1}{20\cdot12^2}\left\{c^4+10c^3+19c^2-22c\right\}+E=\frac{1}{12^2}\left(c^3-3c+2\right)$$

$$E=-\frac{1}{12^2\cdot20}\left(c^4-10c^3+19c^2+38c-40\right)$$

$$=-\frac{1}{20^2\cdot12}\left(8\cdot{}^*5_{c-1}+48\cdot{}^*5_{c-2}+56\cdot{}^*5_{c-3}+32\cdot{}^*5_{c-4}\right);$$

whence

$$\left({}_5P_x\right)=\frac{1}{20.12^2}\left\{x^4+10x^3+19x^2-22x-8.{}^*5_{c-1}-48.{}^*5_{c-2}\right.$$
$$\left.-56.{}^*5_{c-3}-32.{}^*5_{c-4}\right\}.$$

Let now $({}_5P_x)'$, the sum of the $e+1$ terms,

$$-\frac{1}{12^2}\left(9\overline{x-1}.{}^*2_{x-2}+9.\overline{x-6}.{}^*2_{x-7}+,\&c.+9(c-1).{}^*2_{c-2}\right),\quad (G)$$

be supposed to be

$$\left({}_5P_x\right)'=Ax^2+Bx+(Cx^2+Dx+E)^*2_{x-1}+F,$$

$$-\left({}_5P_{x-5}\right)'=-Ax^2+(10A-B)x-(Cx^2-10Cx+25C$$
$$+Dx-5D$$
$$+E)^*2_{x-6}-F-25A$$
$$+5B.$$

The sum of these is

$$\left[{}_4P_{x-1}\right]'=\frac{-1}{12^2}\left(9.x.{}^*2_{x-2}-9.{}^*2_{x-2}\right)$$

From this we learn that $C=0$, whether x be even or odd; and thence that

if x be even, $10A-D=-\frac{9}{12^2}$, and that,

if x be odd, $10A+D=0$;

whence $A=-\frac{9}{20\cdot12^2}$, $D=\frac{90}{20\cdot12^2}$.

Again, if x be even,

$$-25A+5B+5D-E=\frac{9}{12^2}, \text{ and}$$

if x be odd, $-25A+5B+E=0$, *i.e.*,

$$5D-2E=\frac{9}{12^2}=\frac{450}{20\cdot12^2}-2E,$$

$$\text{or, } E=\frac{135}{20\cdot12^2};$$

$$\text{and, } 5B=25A-E=\frac{-25.9-135}{20.12^2}$$

$$B=\frac{-72}{20.12^2}.$$

We have now deduced that

$$\left({}_5P_x\right)'=\frac{1}{20.12^2}\left(-9x^2-72.x+(90x+135)*2_{x-1}+F\right).$$

When $x\overline{\equiv}5=c$, this must be equal to the single circulator

$$-\frac{1}{12^2}(9c.*2_{c-2}-9.*2_{c-2}),$$

for $({}_5P_{x-5})'$ has no terms at all. Therefore

$$-9c^2-72c+(90c+135).*2_{c-1}+20.12^2.F$$
$$=(-180c+180)*2_{c-2},$$

$$F=\frac{1}{20.12^2}\left(9c^2+72c-90c-90c*2_{c-2}-135.*2_{c-1}+180.*2_{c-2}\right)$$
$$=\frac{1}{2880}\left(-144.*5_{c-1}-108.*5_{c-3}-108.*5_{c-4}+0.*5_c\right).$$

It remains to find the sum of the constant circulators in ${}_4P_{x-1}$, ${}_4P_{x-6}$ $\cdots$ ${}_4P_{c-1}$, to $(e+1)$ terms; $x=5e+c$; $c>0$.

The constant in ${}_4P_x$ being $\Sigma a_r.*12_{x-r}$, that in ${}_4P_{x-1}$ is $\Sigma a_r.*12_{x-1-r}$, that in ${}_4P_{x-6}$ is $\Sigma a_r.*12_{x-6-r}$, that in ${}_4P_{x-1-5m}$ is $\Sigma a_r.*12_{x-1-5m-r}$. When $5m$ is a multiple of 12, a_p will appear with the same circulator which it affects in ${}_4P_{x-1}$; for $*12_{x-1-12n-p}=*12_{x-1-p}$. As m cannot be less than 12, a_p will affect twelve different circulators $*12_{x-\theta}$ in the first twelve functions ${}_4P_{x-1}$, ${}_4P_{x-5}$, &c.; and again the same 12 in the

next twelve functions, so that $12h$ successive functions ${}_4P_{x-1}$, &c., will contain h times the term

$$\frac{1}{12^2}.a_p\{*12_x+*12_{x-1}+\ \cdots\ +*12_{x-11}\}=\frac{1}{12^2}a_p,$$

h times for every value of p.

If then $e+1$ be $12h+k$, $x=5e+c$, giving

$$h=\frac{1}{60}\big(x-5\,(k-1)-c\big),$$

the sought sum of the constant circulators will be

$$\frac{1}{12.^260}.\big(x-5(k-1)+c\big)\Sigma a_r \text{ from } r=0 \text{ to } r=11,$$

$$+\frac{1}{12^2}\ \Sigma a_r\big(*12_{x-1-r}+\ \cdots\ +*12_{x-1-5(k-1)-r}\big),\ \text{to } k \text{ terms}$$

$12_{x-\theta}$:

that is, if $x=12m+p+1$, since $\Sigma a_r=a_0+a_1+\cdots+a_{11}=-78$,

$$-\frac{26x}{12.^220}+\frac{26(5(k-1)+c)}{12.^220}$$

$$+\frac{20}{12.^220}\big(a_p+a_{p+7}+a_{p+12}a_{p+9}+, \text{ to } k \text{ terms}\big);$$

for $*12_{x-p-1}$, the only circulator that does not vanish, is affected by a_p+a_{p+7}, &c., in that order, the subindices increasing by 7, or, which is the same thing, retreating by 5, upon the circle $(a_0\,a_1\,a_2\cdot\cdot a_{10}\,a_{11}\,a_0\cdot\cdot)$. Adding now the terms just found to $({}_5P_x)+({}_5P_x)'$, putting $90x-90x.*2_x$ for $90*2_{x-1}$ found in $({}_5P_x)'$, and remarking that, in the last found expression,

$$26c=26.*5_{x-1}+52.*5_{x-2}+78.*5_{x-3}+104.*5_{x-4}+130.*5_x,$$

we have finally,

$${}_5P_x=\frac{1}{2880}\Big\{x^4+10x^3+10.x^2-30x-90x.*2_x$$

$$+135.*2_{x-1}+130(k-1)$$

$$+130.*5_x-126.*5_{x-1}+4*5_{x-2}-86.*5_{x-3}-36.*5_{x-4}$$

$$+20[a_p+a_{p+7}+a_{p+12}+\ \cdots\ +a_{\overline{p+7\cdot(k-1)}};(\text{to } k \text{ terms})]\Big\};$$

where $x=5.(12h+k-1)+c=12r+p+1$; $c<7$, $k\overline{\overline{>}}0$; and a_p, a_{p+7}, a_{p+2}, &c., are the p^{th}, $(p+7)^{th}$, $(p+14)^{th}$, &c., of the circle $a_0\ a_1\ a_2\ \cdots\ a_{10}\ a_{11}\ a_0\ \cdots$, the co-efficients of $\frac{1}{12^2}$ (12_{x-0}, 12_{x-1}, &c.), in ${}_4P_x$; that is, a_p, a_{p+7}, &c., are, in that order, the series,

$$\begin{array}{cccccccccccc} a_0 & a_7 & a_2 & a_9 & a_4 & a_{11} & a_6 & a_1 & a_8 & a_3 & a_{10} & a_5 \\ 0 & 5 & -20 & -27 & 32 & -11 & 36 & 5 & 16 & -27 & -4 & -11, \end{array}$$

of which k terms are to be added together, beginning with a_p, and then multiplied by 20.

There is no difficulty in reducing the terms free from x, the periodic constant, to the form $\Sigma d_p.{}^*60_{x-p}$, where

$d_0=0$, $d_1=+9$, $d_2=+104$, $d_3=-351$, $d_4=-576$, $d_5=905$,
$d_6=-216$, $d_7=-351$, $d_8=-256$, $d_9=+9$, $d_{10}=+360$, $d_{11}=-31$,
$d_{12}=-576$, $d_{13}=+9$, $d_{14}=+104$, $d_{15}=+225$, $d_{16}=-576$, $d_{17}=+329$,
$d_{18}=-216$, $d_{19}=-351$, $d_{20}=+320$, $d_{21}=+9$, $d_{22}=-216$, $d_{23}=-31$,
$d_{24}=-576$, $d_{25}=+585$, $d_{26}=+104$, $d_{27}=-351$, $d_{28}=-576$, $d_{29}=+329$,
$d_{30}=+360$, $d_{31}=-351$, $d_{32}=-256$, $d_{33}=+9$, $d_{34}=-216$, $d_{35}=+545$,
$d_{36}=-576$, $d_{37}=+9$, $d_{38}=+104$, $d_{39}=-351$, $d_{40}=+0$, $d_{41}=+329$,
$d_{42}=-216$, $d_{43}=-351$, $d_{44}=-256$, $d_{45}=+585$, $d_{46}=-216$, $d_{47}=-31$,
$d_{48}=-576$, $d_{49}=+9$, $d_{50}=+680$, $d_{51}=-351$, $d_{52}=-576$, $d_{53}=+329$,
$d_{54}=-216$, $d_{55}=+225$, $d_{56}=-256$, $d_{57}=+9$, $d_{58}=-216$, $d_{59}=-31$.

These numbers are obtained from the formula thus; *e.g.*,

$$x=60h+32=5\cdot(12h+7-1)+2=12r+7+1$$
$$x=60h+40=5(12h+8-1)+5=12r+3+1$$
$$x=60h+49=5(12h+10-1)+4=12r+0+1.$$

The first has $k=7$, $p=7$, and ${}^*5_{x-2}=1$,
The second has $k=8$, $p=3$, and ${}^*5_x=1$,
The third has $k=10$, $p=0$, and ${}^*5_{x-1}=1=-{}^*2_{x-1}$;

therefore $d_{32}=6\cdot130+4+20\{(a_7+a_2+a_9+a_4+a_{11}+a_6+a_1=)-52\}=784-1040=-256$

$d_{40}=7\cdot130+130-20\{(a_3+a_{10}+a_5+a_0+a_7+a_2+a_9+a_4=)-52\}=1040-1040=0$

$d_{49}=9\cdot130+135-36+20\{a_0+a_7+a_2+a_9+a_4+a_{11}+a_6+a_1+a_8+a_3=)-63\}=1269-1260=9.$

It is to be observed that the largest of these is $d_5=905$, a number less than $\frac{1}{2}\cdot 2880$; whence it appears that ${}_5P_x$ is always the nearest integer to the sum of its terms in x.

We may now briefly deduce ${}_6P_x$, which is made up of $({}_6P_x)$ a sum of algebraic terms, of $({}_6P_x)'$ a sum of terms containing circulating co-efficients of x, and a sum of terms of the form $d'_\theta \cdot {}^*60_{x-\theta}$. Writing first

$$[{}_5P_{x-1}]=\frac{1}{2880}\left\{(x-1)^4+10.(x-1)^3+10(x-1)^2-30.(x-1)\right\}$$
$$=({}_6P_x)-({}_6P_{x-6})$$
$$=\begin{cases}+Ax^5+Bx^4+Cx^3+Dx^2+Ex+F,\\ -A(x-6)^5-B(x-6)^4-C(x-6)^3-D(x-6)^2-E(x-6)\\ \qquad -F:\end{cases}$$

we obtain the equations

$$A\cdot 5\cdot 6=\frac{1}{2880};\quad \therefore A=\frac{1}{30}\cdot\frac{1}{2880}$$
$$B\cdot 6\cdot 4-A\cdot 10\cdot 6^2=\frac{6}{2880};\quad \therefore B=\frac{3}{4}\cdot\frac{1}{2880}$$
$$C\cdot 6\cdot 3-B\cdot 6^3+A\cdot 10\cdot 6^3=\frac{-14}{2880};\quad \therefore C=\frac{38}{9}\cdot\frac{1}{2880}$$
$$D\cdot 6\cdot 2-C\cdot 6^2\cdot 3+B\cdot 6^3\cdot 4-A\cdot 5\cdot 6^4=\frac{-24}{2880};\quad \therefore D=0$$
$$E\cdot 6-D\cdot 6^2+C\cdot 6^3-B\cdot 6^4+A\cdot 6^5=\frac{31}{2880};\quad \therefore E=-\frac{841}{30}\cdot\frac{1}{2880}$$

Wherefore

$$({}_6P_x)=\frac{1}{2880}\left\{\frac{x^5}{20}+\frac{3x^4}{4}+\frac{38x^3}{9}-\frac{841x}{30}\right\}+F.$$

Now since, x being $=6e+c$, and $c\angle 7$, ${}_6P_{x-6}$ has no terms at all, we must have

$$({}_6P_c)=[{}_5P_{c-1}];\text{ or}$$
$$\frac{1}{2880}\left\{\frac{c^5}{30}+\frac{3c^4}{4}+\frac{38c^3}{9}-\frac{841c}{30}\right\}+F=\frac{1}{2880}\left\{(c-1)^4+10(c-1)^3\right.$$
$$\left.+10(c-1)^2-30(c-1)\right\}.$$

which gives for F

$$F=\frac{1}{2880}\Big\{\Big(-24-\frac{19}{36}\Big)\cdot{}^*6_{x-5}-\frac{299}{9}\cdot{}^*6_{x-4}-(22+\tfrac{3}{4})^*6_{x-3}$$
$$+\frac{2}{9}\cdot{}^*6_{x-2}+\Big(23+\frac{1}{36}\Big)\cdot{}^*6_{x-1}\Big\}$$

Next, to find $({}_6P_x)'$, we have

$$[{}_5P_{x-1}]'=\frac{1}{2880}(-90x\cdot{}^*2_{x-1}+90\cdot{}^*2_{x-1}),$$

$$({}_6P_x)'=x\cdot F'x+(A'x^2+B'x+C')^*2_{x-1}+G,$$

$$({}_6P_{x-6})'=\overline{x-6}\cdot F'_{(x-6)}+\big(A'_{(x-6)^2}+B'_{(x-6)}+C'\big).(^*2_{x-7}=)^*2_{x-1}$$
$$+G,$$

the first being equal to the difference of the other two. As this difference has no terms at all when x is even, we must have

$$x.F'x=(x-6)F'_{x(-6)},$$

whatever be x, which requires that all the co-efficients in $F'x$ should be zeros. When x is odd,

$$12A'=-\frac{90}{2880},\quad\text{or}\quad A'=\frac{-1}{2880}\times\frac{90}{12},$$

and $$-36A'+6B'=\frac{90}{2880},\quad\text{or}\quad B'=-\frac{30}{2880},$$

whence

$$({}_6P_x)'=\frac{1}{2880}\Big(-\frac{90x^2}{12}-30x\Big)^*2_{x-1}+G+C'^*2_{x-1}.$$

Now $({}_6P_{x-6})'$ has no terms at all, if $x\overline{\overline{\angle}}\ 6$; whence, if $x=6e+c$, $c\angle 7$,

$$[{}_5P_{c-1}]'=({}_6P_c)',\ \text{or}$$

$$\frac{1}{2880}(-90c.^*2_{c-1}+90.^*2_{c-1})=\frac{1}{2880}\Big(-\frac{90c^2}{12}-30c\Big)^*2_{c-1}+G$$
$$+C'\cdot{}^*2_{c-1}.$$

Therefore $G=0$, and

$$2880C'=\frac{90}{12}c^2-60c+90,$$

$$*2_{c-1}\cdot C'=\frac{1}{2880}\left\{*6_{x-1}\cdot 37\tfrac{1}{2}-*6_{x-3}\cdot 22\tfrac{1}{2}-*6_{x-5}\cdot 22\tfrac{1}{2}\right\},$$

because $*2_{x-1}=*2_{c-1}$; whence, by addition of F,

$$*2_{c-1}C'+F=\frac{1}{60^2 12^2}\left\{0\cdot 6_x+10895\cdot *6_{x-1}+40\cdot *6_{x-2}-8145\cdot *6_{x-3}\right.$$
$$\left.-5980\cdot *6_{x-4}-8465\cdot *6_{x-5}\right\},$$

which is the constant in $({}_6P_x)+({}_6P_x)'$.

We have next to sum the periodic constants in the $(e+1)$ terms

$${}_5P_{x-1}+{}_5P_{x-7}+{}_5P_{x-13}+\ldots$$

which are all of the form $d_m\cdot *60_{x-n}$. If we write

$$e+1=10h+k,\ x=60h+6(k-1)+c=60h+p+1,$$

it is evident that no circulator but $*60_{x-p-1}$ can have value. This will be affected in ${}_5P_{x-1}$ with d_p, in ${}_5P_{x-7}$ with d_{p-6}, &c., the subindex retreating always by six on the circle

$$d_0\ d_1\ d_2\ \ldots\ldots\ d_{58}\ d_{59}\ d_0\ d_1\ \ldots$$

The co-efficient of $*60_{x-p-1}$ will have the terms

$$d_p+d_{p-6}+d_{p-12}+\ \ldots\ +d_{p-54}+d_{p-60}+\ \ldots$$

of which the eleventh term d_{p-60} is identical with d_p, the same ten terms continually recurring.

If then $e+1=10h+k$,
our sought sum is

$$\frac{h}{2880}\left(d_p+d_{p-6}+\ \ldots\ +d_{p-54}\right),\ \text{for } k=0;$$

say $\frac{h\mathrm{D}p}{2880}$, where $h=\frac{1}{60}\left(x-6(k-1)-c\right)$;

and if $k>0$, we shall simply have, besides this, as part of the sum,

$$\frac{1}{2880}\left(d_p+d_{p-x}+d_{p-12}+\ \cdots\ \text{to } k \text{ terms}\right)$$

The quantity D_p is the sum of that column of ten numbers d_0, d_1, &c., above given in ${}_5P_x$, which contains d_p. That is,

$$D_p = {}^*6_x \cdot 2642 - {}^*6_{x-1} \cdot 2808 - {}^*6_{x-2} \cdot 558 + {}^*6_{x-3} \cdot 392 - {}^*6_{x-4} \cdot 558 - {}^*6_{x-5} \cdot 2808;$$

for, when $x=1$, $p=0$, &c.

Substituting this value of D_p, and for h its equivalent in terms of x, k, and c, then adding the sum just found to $({}_6P_x) + ({}_6P_x)'$, we obtain the expression following:—

$$\begin{aligned} {}_6P_x = \frac{1}{60^2 \cdot 12^3} \Big\{ & 6x^5 + 135x^4 + 760x^3 - 5046x \\ & - (1350x^2 + 5400x) {}^*2_{x-1} \\ & + 7926x \cdot {}^*6_x - 8424x({}^*6_{x-1} + {}^*6_{x-5}) \\ & + 1176x \cdot {}^*6_{x-3} - 1674x({}^*6_{x-2} + {}^*6_{x-4}) \\ & - 47556k \cdot {}^*6_x + (50544k - 42120) {}^*6_{x-1} + (10044k \\ & \qquad - 6696) {}^*6_{x-2} \\ & - (7056k - 3598) {}^*6_{x-3} + (10044k - 3348) {}^*6_{x-4} + (50544k \\ & \qquad - 8424) {}^*6_{x-5} \\ & + 180(d_p + d_{p-6} + d_{p-12} + \cdots \text{ to } k \text{ terms}) \Big\}; \end{aligned}$$

where $x = 60h + 6 \cdot (k-1) + c$; $k \overline{\overline{>}} 0$; $c < 7$, > 0; $x - 1 = 60h + p$; and d_p is the coefficient of ${}^*60_{x-p}$ in ${}_5P_x$.

Since k may have ten different values 0, 1, 2 . . . 9, the constant circulator is of 60 terms, and of the form $\Sigma f_p \cdot {}^*60_{x-p}$, to which form it may appear necessary to reduce it, if ${}_7P_x$ is to be found from ${}_6P_x$, as this is found above from ${}_5P_x$.

I shall content myself with a few observations by way of shewing that this reduction is at least unnecessary to prove, what we may reasonably expect from our expressions for the 5-partitions, the 4-partitions, &c. of x, that the value of ${}_6P_x$ is the integer nearest to the sum of the terms in x.

In order to see that this is so, it is necessary to be convinced that the circulating constant is always numerically less than $\frac{1}{2} \cdot (60^2 \cdot 12^2) = 259200$. When ${}^*6_x = 1$, p is one of the ten numbers 5, 11, 17 . . . 59; and it is easily seen by inspection of the quantities d_p in ${}_5P_x$, that no consecutive k of d_5,

d_{11}, &c. can be taken, which shall not have a positive sum, (unless $k=1$) and that 180 times this sum, added to $-47556k$, will always give a number nearer zero than -259200.

When $*6_{x-1}=1$, p is one of the ten numbers 0, 6, 12 . . . 55; and inspection readily shows that no k of the set d_0, d_6, &c. can be taken consecutively, which shall not have a negative sum, (unless $k=1$) and shall not, when multiplied by 180, make with $50544k-42120$ a number less than 259200. By continuing this kind of inspection, of $(d_p+d_{p-6}+$ . . to k terms) for any value $*6_{x-c}=1$, the reader may convince himself that the number ${}_6P_x$ is really the integer nearest to the sum of the terms in x; and the only proof that appears in any case practicable of this point, is by inspection of the constant in ${}_6P_x$. He will therefore excuse me, thus far, from the trouble of writing down the 60 terms of that constant.

Neither do I think it necessary to have them assigned in order to the finding of ${}_7P_x$; for, in fact, there is a method of obtaining the value of D_p above written, from the terms in x of ${}_5P_x$, without any knowledge of the numbers d_p in that expression; and I am convinced, that all the terms in x of ${}_7P_x$ can by the same method be deduced from the terms in x of ${}_6P_x$. But I shall reserve the proof of this, which is too long to be here inserted, for a future communication. It is very important that a method should be made out of finding ${}_nP_x$ from the terms in x of ${}_{n-1}P_x$, without the enormous labour of specifying every term in the constant circulator of ${}_{n-1}P_x$; for the number of those terms increases very rapidly, as we advance to higher values of n.

The preceding results, as far as the expression for ${}_5P_x$, are identical with those given by Sir John Herschel in the Transactions of the Royal Society for 1850; "On the algebraical expression of the number of partitions of which a given number is susceptible." In that memoir the reader may see some account of what has been before done on this subject by Prof. De Morgan and Mr. Warburton; and he will perhaps

think, that the matter is new enough, and difficult enough, to make it worth while that it should be shown, as in this paper, that the problem, which Sir John Herschel has so elegantly mastered by a somewhat formidable analysis, may be made to yield to more elementary methods. I regret that I have not seen, nor have any means of seeing, so far as I know, within 150 miles of Manchester, what Prof. De Morgan has written on this subject in the *Cambridge Mathematical Journal.*

VII.—*Memoir of the Rev. John Lawson, B.D., Rector of Swanscombe, Kent.*

By T. T. Wilkinson, F.R.A.S., &c.

[*Read February 7th*, 1854.]

The Rev. John Lawson was one of the most distinguished geometers of the last century. From a very early period of his studies he appears to have devoted considerable attention to pure geometry, and after the death of Professor Thomas Simpson, he took the lead in promoting the study of geometrical constructions and the ancient geometrical analysis. His taste in these matters was formed upon the models left us by Pappus and the restorers of the works of the ancient Greek geometers, many of whose writings he afterwards rendered accessible to English students, and his numerous geometrical *opuscula* in the different mathematical periodicals to which he contributed, may be referred to as proofs of the success which attended his efforts to resuscitate the correct forms of the ancient Greek geometry.

Mr. Lawson was the eldest son of the Rev. Thomas Lawson, vicar of Kirkby, in the county of Lincoln. He was educated at the Boston Grammar School under the care of Mr. Robinson, and was admitted a Sizar at Sidney Sussex College, Cambridge, on the 5th December, 1741. He obtained his B.A. degree in 1745, and was elected a Fellow of his college December 3rd, 1747. In 1749 he proceeded in due course to the M.A. degree, and was admitted B.D.

in 1756. His name appears as college tutor till the beginning of 1760, and he also held various college offices from 1748 to 1757. He was for a considerable period Senior Fellow of his college, and as such, in 1759, was instituted to the rectory of Swanscombe, in Kent, which he continued to hold until his death.

During his residence at Cambridge, he had become known as an ardent admirer of the works of Apollonius. The valuable fragments of geometrical research contained in the Mathematical Collections of Pappus had led him to examine, with critical attention, all the efforts of the moderns to restore these "second elements;" and shortly after his removal to Swanscombe, he resolved to devote a portion of his means and leisure to the translation and publication of the most successful of these restorations. In the Preface to the Seventh Book of the Mathematical Collections, Pappus Alexandrinus has enumerated those works which were then usually studied after the Elements of Euclid. They consisted of the Book of Data and a Treatise on Porisms, by the editor of the Elements;—the Section of Ratio and the Section of Space;—the Treatises on Determinate Section, Tangencies, Inclinations, Plane Loci and the Conic Sections;—all of which we owe to the fertile genius of Apollonius, the great geometer of Perga. The interest attaching to these lost treatises, of which scarcely anything has come down to our times except a few preparatory Lemmas, had induced several of the most able geometers, both of our own and other countries, to attempt the reconstruction of the originals from the obscure hints given of their contents by Pappus, and among the most successful of the adventurers into these obscure regions of geometrical science, are our own countrymen, Dr. Halley and Dr. Simson, of Glasgow. The former has restored the Sections of Ratio and of Space, both of which are conceived in the true spirit of the ancients; and the latter has been equally successful in reproducing the Loci, the Determinate Section,

and the Treatise on Porisms, confessedly one of the most obscure and difficult enigmas of antiquity. No two opinions are now held as to the merits of these restorations;—their contents, if not actually identical with those in the lost treatises, are considered by the best judges to differ from them only in point of excellence. About a century before this period several continental geometers of eminence had succeeded in restoring some of the remaining treatises, but as these attempts were written in Latin, and had become very scarce, Mr. Lawson determined to present them to the English reader in his own language, and thereby, at least for a time, rescue them from that oblivion into which they were rapidly falling. His first step towards accomplishing this desirable object was the publication of a translation of "The Two Books of Apollonius Pergæus concerning Tangencies, as they have been restored by Franciscus Vieta and Marinus Ghetaldus." This work was published at Cambridge in 1764, and contained, besides an excellent condensation of what had been effected by Vieta and Ghetaldus, several additional propositions on the same subject by Mr. Lawson himself, and a selection from the writings of Mr. Thomas Simpson. In the second edition, London, 1771, several minor oversights were corrected and a "Second Supplement" added, "being M. Fermat's Treatise on Spherical Tangencies."

The description of a circle to touch three given circles has always formed a favorite subject for the contemplation of geometers, and the solution of the various cases, when straight lines or points are substituted for one or more of the given circles, has occupied the attention of many of the most able mathematicians. The publication of this tract had the effect of once more directing attention to different modes of treating the general problem, which have since resulted in the complete and elegant constructions of Swale, Hearn, Bobillier, and Gergonne.

It must not, however, be supposed that Mr. Lawson

neglected the more immediate duties of his high vocation while thus engaged in promoting the study of the ancient geometrical analysis. He was a man of fervid but unassuming piety, and had ever the temporal and spiritual welfare of his parishioners at heart. His discourses always breathed the spirit of pure and earnest piety, and not unfrequently bore the marks of originality and deep study. A volume of "Occasional Sermons on the Office and Duty of Bishops," which was published at London in 1765, was very favorably received by the theological critics of the day, while their style and matter do equal credit to the head and heart of their author. During the interval which elapsed between this and his next publication, Mr. Lawson entered into an extensive correspondence with the cultivators of his favorite science, and in common with his talented neighbour and associate, the Rev. William Crakelt of Northfleet, became one of the most distinguished contributors to the mathematical periodicals. The *Ladies' Diary*, *Hutton's Mathematical Miscellany*, the *Gentleman's Diary*, the *London Magazine*, and the *British Oracle*, contain many elegant geometrical questions and solutions from his pen, almost all of which bear the impress of his good taste and extensive reading. To the latter work he furnished several translations of geometrical and other papers from the foreign transactions, and the seventh number contains a "Synopsis of Data for the Construction of Plane Triangles," which was afterwards expanded and published as a separate treatise in 1773. This was a most useful publication to geometricians, since it contained abundant references to almost every work then known which treated on geometrical problems. Professor Leybourn subsequently published a much enlarged edition of this tract, and Mr. John Farey, of London, has followed up Mr. Lawson's ideas in several of the concluding numbers of the *Gentleman's Mathematical Companion.*

"The two books of Apollonius Pergæus, concerning Determinate Section, as they have been restored by Willebrordus Snellius," appeared in 1772; to which were added a *second* restoration of "the same two books by William Wales," subsequently mathematical master of Christ's Hospital, London. Mr. Lawson was induced to publish this translation from the circumstance that "these pieces of Snellius" were "exceedingly scarce in England. His Resuscitata Geometria de Sectione Rationis et Spatii, 1607," he had "never once had an opportunity of seeing" and "lest the other tract, De Sectione Determinata, should undergo the same fate as the original Apollonius, [he] was determined to rescue it therefrom, or respite it at least for a time, by putting it into an English dress." Both this, however, and Mr. Wales's more successful effort are now entirely superseded by the elaborate restoration left us by Dr. Robert Simson in his Opera Reliqua, which not only includes the propositions noticed by Snellius and Wales, under the purest forms of the ancient geometry, but adds a third and fourth book on the same subject to those enumerated by Pappus. The publication by which Mr. Lawson is best known is the "Dissertation on the Geometrical Analysis of the Antients; with a Collection of Theorems and Problems, without Solutions, for the Exercise of Young Students." It was published anonymously at Canterbury in 1774, but its contents and the nature of the subject left no doubt in the minds of geometers as to who was the real author. At this period there was but one person known to the mathematical world who was likely to undertake such a discussion, and his *propria persona* was all but revealed in an advertisement attached to the work. In this dissertation the true principles of the ancient geometrical analysis are very clearly laid down and illustrated by a variety of examples, both original and selected; various methods of conducting the solution of the same geometrical proposition are instanced for the encouragement of young students, and

as "specimens of what kind of solutions" he would have them "endeavour after." Most of the collection of theorems and problems was selected from Dr. Stewart's Propositiones Geometricæ and his General Theorems; but these works were so little known to English geometers at the time, that this selection is now usually referred to as Lawson's Theorems. From a notice which appears in the *London Magazine* for May, 1777, it is evident that Mr. Lawson intended "to publish a variety of Demonstrations, by different authors, of the Theorems and Problems annexed to his Dissertation on the Geometrical Analysis of the Antients." With that view he entrusted his manuscript for inspection and revision to several of his friends, and among others to the very able geometer, Mr. Jeremiah Ainsworth, of Manchester. But his intention of publication was frustrated by the hand of Death; and the existence of this valuable manuscript at this distance of time is more than doubtful. The collection, however, was not destined to remain without solutions. Mr. Leybourn reprinted the Dissertation in his *Mathematical Repository*, and a much enlarged edition was issued by Mr. Michael Fryer, at Bristol, in 1811. The Theorems were also demonstrated by Messrs. Swale, Campbell, and Nicholson, in the *Repository*, and an elegant connected discussion of the same series, by the Rev. Charles Wildbore, has, since his death, been printed in the second volume of the New Series of the Memoirs of the Manchester Philosophical Society. By this publication Mr. Lawson gave permanency to his reputation as a geometer, and the treatise by which this was effected still retains its value as a guide to the beauties of the Greek geometry.

In 1776 the posthumous works of Dr. Simson were printed for private distribution at Glasgow, but since these were wholly written in Latin, Mr. Lawson determined once more to benefit the English reader by publishing a translation of the "Treatise on Porisms," contained in that admirable

work. Accordingly, during the following year, the first seventeen propositions were published at Canterbury, "in the hope that all lovers of geometry [would] encourage the work," not only "on account of the great curiosity of the subject," but also "on account of the great abilities of the author, who has always been esteemed the first geometer of the age." It does not, however, appear that the translator's hopes were realized; for although he proposes shortly to complete the work in "three more such [monthly] numbers," the sale did not warrant his proceeding with the translation. He subsequently furnished an English version of Maclaurin's "Treatise on the General Properties of Geometrical Lines" for the fourth edition of that author's Algebra, London, 1779, and these, together with the solution of "An Arithmetical Problem," printed anonymously, complete the catalogue of the published writings of this zealous and able geometer. He died at Chislehurst, in Kent, on the 13th of November, 1779. His abilities were favorably noticed in the obituary of the *Gentleman's Magazine* shortly after, and the following tribute to his public and private worth was written by his friend, the Rev. Charles Wildbore, then editor of the *Gentleman's Diary*:—

"On the dark mountains of death's dreary dale,
My weeping muse begins her mournful tale.
My *Lawson* gone, my kindest friend no more!
Who now shall wish to con my trifles o'er?
Who now like him fine taste shall teach our youth?
Or grace with elegance the force of Truth?
In this attempt, his early lamp my friend
Oft trimmed—nor midnight saw his taper end.
But oh! no learning stays the parting breath;
Nor parts, nor arts, shield from the shafts of death.
Fair *Science*, mourn thy loss. His generous mind
To the free friend the brother's kindness joined,
And aimed to please and profit all mankind."

VIII.—*On Sewage and Sewage Rivers.*

By Robert Angus Smith, Ph. D., F.C.S.

[*Read January 23rd*, 1855.]

The removal of refuse from a town gains importance as the town increases, rising at last to be a matter of the greatest moment and surrounded with the greatest difficulties. At the same time, if we take only theoretical grounds, we may say that the removal of refuse must become easier as a town increases, because there is an increased combination of individuals to share the trouble and the expense. This method of viewing the matter I believe to be the true one, whatever practice may say as to the difficulties. The modes of removing refuse are many, but they may very readily be reduced to two; 1st, The removal from the place of original location by carts or any other means of overland carriage; 2nd, The removal in tubes or pipes with an abundance of water. The first method is the most general, it is the original method; it may be said to be the universal method, the exceptions to it are so few. This universality does not occur from any superiority which it possesses, but from its simplicity, although I probably use that word in a wrong sense; I ought rather to say, from the fact that it arises naturally when the least amount of thought is directed to the subject. The refuse is deposited in the nearest convenient place, and it is removed when it becomes intolerable. This plan has been adopted in all ages and countries with more or less care. From the filthy

savage up to the refined inhabitant of Paris, all classes of people have made use of it. Simple as it is to begin with, the structure of cities no sooner becomes complex than this system becomes complex too. Space becomes of great value, and the places for deposit in towns cannot be spared. Time becomes of great value, and workmen to remove the refuse are expensive; distance from the fields increases, and the difficulties as well as the nuisance of the removal increase with it.

The simplicity of the plan then ceases. Either a large space must be occupied with the refuse in the town, as with us; or a small space frequently emptied, as at Paris. In the first case, we have a city with a row of ashpits and receptacles of soil equal in length with the rows of our houses, covering a large per centage of the ground of our towns, and accumulating enormous amounts of impure matter. In the second, we have a house subject to unwholesome inconveniences, far exceeding, certainly, all that we suffer here, the want of space confining it to the house, and the removals being uncomfortably frequent. The simplicity is lost from another cause also, the labour has become one which requires great skill to prevent discomfort and disease, whilst the whole plan itself, if we judge from results in Paris, is obliged to give way at last and seek the assistance of the second method alluded to—the use of conveyance in tubes by means of water.

Under the most refined management of this system in Paris the refuse is conveyed into dry closets, as they may be called, having no water to wash down the soil, which is conveyed either into a moveable cylinder of zinc or into a cesspool in the cellar. If a moveable cylinder is used, it is at once conveyed away by carts, the more liquid part flowing away by an overflow pipe, the solid remaining. If the cesspool is used, it is emptied once or twice a year by means of a pump. The deposit, which is of the thickness of very wet mud, is

pumped into airtight barrels, the pump-tube being made to dip down to the bottom of the cesspool so as to bring up the solid and leave the liquid. Some disinfecting liquid, chloride of zinc, is put into the barrel so as to prevent any nuisance in the streets. When this deposit has been pumped up into the barrels, it is carted off to La Villette or taken to the canal boats and conveyed by them. Here the barrels are emptied and the contents conveyed by pipes to Bondy. There the matter is allowed to deposit in a large reservoir, or filthy lake, from that it flows to another, where more is deposited, and so on to a fourth, where the deposit is small. The liquid is then used for the manufacture of ammonia and its salts.

The establishment at La Villette consists chiefly of a great underground tank completely arched over, and above this a building consisting mainly of a series of archways, into which the carts may enter to deposit the contents of the barrels into the holes in the floor. The contents flow, as before stated, to Bondy, sent by a forcing pump. Bondy is seven feet higher in level. The pipe is one foot in diameter, made of tinned iron, covered with asphalt. The number of barrels emptied here daily is from 1,200 to 1,500.

This is the manner in which the heavier soil is treated when it is taken from the cesspool. The liquid matter is then disinfected with chloride of zinc, and pumped out into the streets, from which it runs into the sewers. Four men are appointed to do this, three and a foreman. They are provided with test paper, in order to see when the sulphuretted hydrogen is removed. But the smell is beyond their management apparently, as the operation fills the cellars with the most violent stench, and the street has the same unpleasant odour to a great distance. Certainly we may be too particular in such things. A French writer, to whom this subject is dear, considers that the *pruderie* of the English in such matters prevents them from enjoying the great blessings of the Paris method, adding that the dislike of these substances

spoken of is so great in the aristocratic quarters of London that it is not probable that any alteration will be made on the system for a long time.

The other method of having closed receptacles for the soil in the house or even out of the house is also in use, but in practice both the methods have an uncomfortable and dangerous result from the want of water and the impossibility of obtaining any cleanliness without it. As far as the principle is concerned, the continental method, in all its modifications, is merely the ordinary outdoor convenience, so common with us, conveyed into the interior of the house; a place where idleness alone could place it, unless it were connected with abundant means of purification.

The other modification of what may be called the overland means of conveyance is that adopted in this city and neighbourhood, where the material lies open in countless, or I should rather say in 60,000 places, diffusing itself over the whole town, and evaporating as rapidly as the various states of weather allow it, uncurbed in its movements, except by a wall at the side, which is quite unable to confine this result of decay. In one respect we have the advantage that this matter is not inside the house, that the system of building gives room enough behind every house for a yard, and we are not crowded one over the other, or unwholesomely confined on narrow shelves. At the same time we have this disadvantage, that the rivers are not kept pure as at Paris and elsewhere, whilst the land also is rendered impure, and the constant cleanings infest the air. Having a mixture of all systems we have the advantages of none and some of the evils of all.

The advantages of the overland system include the sale of the material, which in Paris is something of consequence, when stated in a certain form; the poudrette which is manufactured is sold at about twenty shillings a ton, but it is not bought eagerly, and in fact is not of very great value. The amount

sold is of course enough to pay abundantly those engaged in the manufacture; but they have made such terms with the municipality as to ensure them a profitable business. It appears, on inquiry, that neither does our primitive method or no-method pay, nor the refined method of Paris. The expense there of cleaning a cesspool is seven francs, and it must be emptied as soon as filled. The expense of cleaning Manchester is about £8,000 a year for the 250,000 inhabitants, making for each about 7d. a year. In Edinburgh the value of the ground, manured by a very careless method of using some of the refuse, has been raised from a trifle to £150,000, which is to be taken as the value of that portion of the manure which is there used, being equal to £7,500 a year. This is the sum which the property would fetch in the market, and the sum the proprietors would be entitled to if the sewage were taken from them, according to certain legal opinions. The proprietors have also had sufficient power in the city councils to prevent any success in depriving them of their privileges.

We may conclude from the practice of these three cities, Paris, Manchester, and Edinburgh, that there is in existence no complete plan for the treatment of the refuse of a town, although the plan in Edinburgh shows that such a system is not only possible, but in the highest degree successful, and only wanting in profit to Edinburgh, because that town has not seen its value in time but has left its riches to those who were more diligent. The experiment is, however, a great one; the subject is one which must now take a most prominent place in our home affairs for many years to come, until it shall be decided that it is as unwise to destroy the property of the country by losing the refuse, as it is to allow goods to be burnt in warehouses and in shipping, as is our custom, without taking the means of precaution which are placed in our reach.

I thought these remarks necessary before bringing the sub-

ject of this paper before you, in order that I might draw the conclusion that, in the two methods mentioned of leading away the refuse in barrels and manufacturing it into poudrette, and of leading it away in carts and selling it without manufacture, no profit is to be expected, but the town or the country must pay a constant price for cleaning; whereas, by leading the refuse away by means of water, a price is obtained more than sufficient to clean the town. Water seems, then, the only successful conveyancer, according to practice, unless, of course, the new Manchester experiment of conveying it by railway should turn out valuable, although by no means likely to do so to any very great extent. Even if it were to turn out profitable, it would still be objectionable from the fact that the town is by its means not preserved in a sufficient state of purity as before mentioned. If, however, the water-closet system be used, the town is not only kept clean but the conveyance is made in the manner that has hitherto turned out most profitable, as at Edinburgh, and which has been found needful, so as to make the other or overland system complete as at Paris; whilst the disgusting manufacture carried on at that place, and occupying so much land, is dispensed with, and the still more disgusting system of clearing adopted here is also done away with, a plan by no means producing such bad results as on the continent, not from any merits of its own, but because there is here scope for extension, and our houses are not confined to the limits of city walls. As the irrigation method at Edinburgh has at present the most decided success, or in other words the conveyance by water been found cheapest even when partially tried, it seems only natural to conclude that the conveyance should be by water the whole way, as would be the case if the English water-closet system were carried out to its full extent. The chief evil connected with that system is the hitherto great loss of the products; and the chief difficulty with regard to irrigation is the obtaining suitable ground in the neighbourhood. The

large supplies of water now coming into our towns has given us a capacity for extending the water-closet into every house, and I believe that it is the true one, in spite of the obstacles placed in its way in our own town. It has fortunately taken hold of England in a manner such as to prevent all power of receding. Removal by water seems to have begun in every large town, ancient and modern, but never at any time brought to perfection, because peace and prosperity and a knowledge of the arts have so seldom endured long in any one place. The tendency of improvement has always manifested itself in the direction of removal by water and by underground sewers. The usual way has been to remove the opening of the sewer to the lower part of the town, but in course of time this portion of the neighbourhood becomes surrounded with inhabitants, and great inconveniences arise; it is then drained into a river or brook, if there be one, and again that becomes a closely inhabited district, whilst the nuisance of the drainage is sufficient from a large town to render impure the largest rivers. This state of affairs is generally of very gradual rise from the beginning; no one can be blamed, no one could have foreseen the evil; as to the end no one need claim much credit for seeing that something must be done; the evil rises up in a hideous form before us all; our capital city appears to be built on a cesspool, instead of a magnificent river, and Manchester becomes a proverb, by giving its rivers and canals such blackness as not only to render them disagreeable, but to cast a shade of gloom on all who come into the town.

Various Methods of Treatment.

The methods of treating the fluid matter of the sewers are few. The practice of allowing it to go into the river has long been objected to. The method of applying it to land, and so taking hold of it before entering the river, although long in gradually increasing practice, was first

brought into comparison with other methods in modern times in England by Mr. Smith, of Deanston, and Mr. Chadwick. Mr. Chadwick's account of it in the general report of the sanitary condition of the labouring classes, gave it, perhaps, the first prominent place among systems, and he has always supported it in the publications of the Board of Health. Smith, of Deanston, published an account of his method in the first report of the Health of Towns Commission. Mr. Cubitt was desirous of having it brought into practice, but could see no plan by which it could be made economical for London. Those who have tried sewage manure are chiefly private persons. It has been found to render land so productive that it yields actually from 70 to 80 bushels of wheat per acre, and has sometimes increased the pasture tenfold. This remarkable result is enough, of course, to justify any probable amount of expenditure. Mr. Wilkins, (in the journal of the Society of Arts,) thinks it would be advisable to use it even if £100 were spent upon an acre, his peculiar method being an expensive one, considering that £10 an acre has been considered a large sum for the improvement of land, only justified by the success attending recent discoveries in draining and manuring. That success must be enormous which ventures to breathe £100 per acre. Such fertility of soil would certainly allow us to build upon farms works of such a kind that health and appearance might also be consulted as well as profit.

Smith's proposal was to irrigate meadows with the sewer water, by overflowing them in the method long in use with ordinary water; Mr. Chadwick recommended the use of the jet and the hose to sprinkle the water over the land, and to save the use of pipes and drains.

Mr. Corbett proposed the use of pipes for the irrigation near Manchester, and recommended a lifting pump at Ordsall or Trafford Moss. Mr. P. H. Holland began the system adopted by Mr. Chadwick and himself, of watering with the

hose; but being compelled to carry the refuse in boats he was obliged to desist. At the same time it became clear that a very short time of such a top dressing as he used was not enough to produce the remarkable results detailed at Edinburgh. Although very strong manure is not needed, very dilute is of little advantage, requiring too much labour and too much water. Mr. Holland added manure to the water which he used, as he could not get it direct from any strong sewer. The sewer water of towns so well supplied with water as Manchester and London cannot be of such value as to allow expensive carriage; whereas there are times of great rains when it is only to a slight degree rendered impure.

Let us suppose that all the water flowing down a Manchester sewer were to be put upon the ground. Let us say there are twenty million gallons from the waterworks, add to this occasionally the rainfall from drainage, over, let us suppose, twenty miles of surface. The land here has quite enough to do with its own rainfall, not knowing how to pass it with sufficient rapidity through the ground, but how are we to convey to it the rainfall of other twenty miles. Let us suppose we have twenty square miles to let it fall upon, there is double the rainfall for it, how damp must that land then be in a county already too damp. But even twenty miles is an enormous extent to cover and not easily obtained, or if obtained not easily managed. If, however, it will be too much to put double the rainfall on, then more than twenty miles must be used, rendering the work still greater and more difficult and expensive.

But this is the mere rainfall during floods filling the sewers too full. What, then, is to become of the twenty million gallons every day of the year besides? To put them upon any land would be, of course, to injure the climate of the district to a great extent, unless the breadth of land were enormous; and to put this water on as irrigation for meadows involves a difficulty inherent in the formation of the land

around us, perhaps, however, a difficulty that is not insuperable, although the climate must always be considered. To put on this water with the hose, is certainly out of the question. It is in fact to form a new waterworks of a reversed kind, and to give out all the water of the present waterworks and more, not by the standing pipes in the streets and houses, such as at present deliver it, but by the hose or flexible pipes held in men's hands continually until all is run out.

If the use of sewage manure were to be generally adopted, the sewers must be carried out of the town; they would then not run into the river, but probably along the river. It would be impossible to remove the water from them as rapidly and as regularly as it flows, so that it would be needful to have a large tank or reservoir. This reservoir would receive all the water which now is supplied by the waterworks; and, in fact, would be a second waterworks on a scale greater than the one at Woodhead. The advocates for sewerage manure say that it may be put on in all weathers; but we cannot suppose that this will occur, neither can we possibly imagine any probable circumstances which would induce the men of Lancashire to stand with hose in hand until that enormous amount of water were put upon the land. It must be done by the irrigation system, or the method must be resorted to of having separate drainage for water closets; by whom it was originally proposed I do not know, but which I have advocated in a short paper on Sanitary economy in some of your hands. My own belief is, that this would be an excellent system; the best hitherto proposed, both as to convenience and to profit. It is unnecessary, however, to dwell long on it. I conceive that if it were adopted, the sewers would produce a manure so strong that it might readily be mixed with the refuse water from the factories, and still be valuable. I do not, however, think that it is essential to use it all liquid. In the above state it might be used liquid near the towns. And here we come to another dif-

ficulty attending all the liquid manure plans, it is that of getting suitable land and sufficiently extensive near towns. I confess I am unable to argue this well, but I am inclined to think that the manure is so abundant that it will readily supply persons to a great distance. If the water closet sewers are kept distinct, it is probable that precipitation and preparation would be essential, as the manure would not be in a fit state to put on land without loss and nuisance; but if the sewer water remain as it is, the distance of carriage and the amount to be put on land seem to be great difficulties, quite insuperable in the way of applying all the refuse matter of a large city. If, again, all of it is not applied, there is no advantage in having any portion applied, as far as the purity of the stream is concerned; at least it is not for us to waste our time thinking on merely a small diminution of the evil.

It has been proposed, also, to take the sewage into a reservoir, and allow it to precipitate. This is the method adopted with the contents of cesspools at Paris, but there the matter is undiluted, and even of that the densest portion only is taken, leaving the liquid to be run off into the sewers. The poudrette formed is not of great value, and sells for much less than our artificial manures, about a pound a ton. The deposit in sewer water ponds was found, in an instance mentioned by Smith of Deanston, to be worth very little. It was sold for one shilling a ton, but the analysis and especially the amount of phosphates is wanting to determine its real worth.

Leaving that aside, the matter valuable for manure is not in suspension merely, and cannot therefore be obtained by subsidence only. For these reasons it has been proposed to filter the sewage water, and this method certainly produces very fair water in appearance, and leaves a great amount of valuable manure in the filter. But the oxidizing power of the soil and of porous bodies is the cause of much waste of

material of pure organic origin, and the ammonia is converted into nitric acid, forming very soluble salts, easily washed away. There is also in no artificial filter, a ready power by which the phosphates can be eliminated.

The mode of using liquid manure only, is in reality the filtration by the use of a natural filter, the ground; and in a case like this, the success is complete. The ground has the power of absorbing a certain amount of salts, especially if united with organic matter, such as the phosphates often are, and the surface to which the liquid manure is applied is so great, that there is no danger whatever of losing much of its value. Filtration on any practicable artificial scale will not produce this result, but will allow much valuable matter to be lost.

The subsidence method and the artificial filtration are both liable to another great objection, that the ammoniacal salts are not taken from solution in the slightest degree. On the Paris plan, the liquid from their highly concentrated manures is used in the manufacture of ammonia and its salts, as it is strong enough to allow of the expense of heating and distilling from retorts into acids which retain it. The slowness of the process of ordinary subsidence is also an objection.

There was proposed, it seems difficult to know by whom at first, a plan for precipitating with lime. There was a commission appointed by Parliament to inquire into it. The preliminary inquiry was held before Sir Henry de la Beche, F. L. Wollaston, Richard Phillips, Esq., and Dr. Lyon Playfair. In 1845, Mr. Wicksted proposed lime for precipitating sewage; and Mr. Higgs, in April, 1846, took a patent for lime. There is a dispute as to who was first in proposing this, but I see that in 1846 also Dr. Stenhouse proposed a plan for precipitating with lime; so that, apparently, the well known clearing property of lime has given rise to the idea in many minds of using it for sewage, and these were published at the time when the subject was very much occupying public

attention. Mr. Calvert has proposed it also for the Medlock, as I am told, with the addition of some original, and I do not doubt valuable, plans for collecting the precipitate without interrupting the flow of the stream.

The inquiry into the plan proposed by Mr. Higgs, to have a reservoir at Bermondsey, in which he would precipitate the sewage by lime, gave rise to some points for consideration, which may be mentioned.

It was stated that the phosphates would precipitate, and that this would take place in about six hours.

It was also said that the sulphuretted hydrogen would be thrown down by lime.

The ammonia would be lost entirely, except such as might be formed from the solid organic matter containing nitrogen, and found in the precipitate; of course, all that came from urine, which gives the greatest portion, was lost.

There was another objection, as this precipitate was to be dried, and in that case the lime would prevent the preservation of the portion of the ammonia left in the solid, at least to a great extent, entirely removing the other portion.

The sulphuretted hydrogen was not quite removed, as was admitted, but it was proposed to be burnt by passing it through the fire. The same thing was to be done with the remaining organic substance which caused the residual smell after the lime had done its utmost towards deodorizing. This plan of burning gases, by passing them over fire or through hot chimnies, is by no means an efficient one, unless the gases be small in quantity and the fire long. I have seen it more than once quite fail. The escaping ammonia was to be retained by means of muriatic acid, which would unite with it meeting in the flue. This is a plan attended with difficulties, unless the flue has very little draught in it. On the whole, then, lime does not seem desirable, because it does not quite destroy the sulphurretted hydrogen, and does not retain the ammonia; otherwise I must allow that it is really a beau-

tiful precipitant, and the water, when drawn from it, appears perfectly pure.

Mr. Higgs did not propose to deal with all the sewage water of London, but only the portion about breakfast time. The amount was too large to manage. That certainly will be a difficulty with London, with Manchester the difficulty is much less, and a trifle, supposing the water closet drainage to be separately treated. He proposed, also, to have rails over the reservoir, so that persons might walk over it, throw down the lime from waggons and stir it about. This makes the matter still more difficult and expensive. Six tons of matter were to be dried daily.

The plan is well worth considering, and the lime is by no means to be at once condemned, when used with proper precautions, although one chemist, Paulet, calls it a vicious method which loses the ammonia and the salts of potash and soda. The precipitate in the case he refers to consisted of

Chalk	44.96
Magnesia	1.32
Phosphoric acid	40.18
Organic matter	13.54
Or loss by fire	100.

This I call rather a brilliant result; we are not given to understand how much ammonia was in this organic matter, but even were there none the amount of phosphoric acid is worth preserving. The French practice so much boasted of actually even now throws away the ammonia and alkaline salts in the liquid which runs into the sewers, retaining only that portion which drains from the dense mass which is transported to Bondy. The use of charcoal as a filter for sewage water is not to be recommended, as little of value is removed. The use of ordinary soil and clay as a precipitant would be better, as they remove a great amount of valuable matter, but this I think scarcely sufficient, although in some circumstances

not to be put aside. As a scientific inquiry the researches of Professor Way, on the absorption of salts by soil, are of much interest and value, explaining the use of soil and its action in nature. He himself does not, however, recommend it as an economical method of collecting the matter of sewage manure.

I am told that Mr. Dyer had a plan of keeping the rivers pure, but I have not heard a full explanation of it. He says that those who dirty the water should clean it; and this, in reference to manufactures, is a point worth your consideration. Those who take into their works pure water might take the trouble of filtering it before they allowed it to go back. Instead of that, there has been an irregularity in the whole management of these affairs, from the tops of the hills of Lancashire down to the very town halls, and, I am sorry to say, a selfishness, in seeking or taking water, which has completely defeated the objects of all. It happens, now, that in one of the wettest climates of England there is a want of water for manufactures, although there is no need for even a small portion of what falls, and one man, by using a few gallons, and sending them back dirty, pollutes a whole stream. There has been an extravagance and waste, in this respect, which has put many to great trouble and expense, and caused an extensive series of water-works, extending over the whole county, and made by private individuals, for the use of their own works. This plan, of allowing no one to send in the impure water from his works, would not, however, be a sufficient cure for the evil we are speaking of. The amount of towns, villages, and isolated houses in this district, is so great, that they alone are sufficient to pollute the streams to a great extent, leaving out the largest town, Manchester. We have, then, to deal with an evil which extends itself along the banks of our streams, from this place to their very source, and in every portion, I might almost say, of both banks. It has been mentioned to me by Mr. M'Dougall, that, to keep the

Irwell pure, every impure stream should be retained and purified before it is allowed to enter the main stream. But this is a plan which will not suit all circumstances, as the river is made impure by drainage direct in many places. Sometimes it is a small sewer, which will not bear separate purification; sometimes it is the trickling out of impurities from the soil—the drainage of dirty streets or land.

Plan for Manchester and South Lancashire.

The plan which I propose has already been published in a skeleton form, but I will endeavour to explain it more fully. I do not pretend to say that the plan is original,—it is made up of the things that I have seen and heard, as most other persons make their plans; but the result, at least, has novelty, and of course, in my opinion, is the best hitherto devised. As a whole, it was new to me.

And first, I begin with the maxim similar to one I have mentioned—that no dirty water should be allowed to go into the river. If this is managed, the river will be clean.

To effect this, every town would carry its drainage to a point out of the town. The sewer water to be then treated by precipitants, and allowed to pass off clean. When there is not a town to be dealt with, but a district, then a certain portion of the houses and works on the river bank will be united into a drainage district, and this sewer water will run into a drain or drains parallel to the river, until there is a sufficient amount collected for precipitation. There will be then a constant succession of tanks, equal to the density of the population. There will also be a continual line of sewage drains as far as the population extends; or, in other words, a dirty river running parallel with the clean one: just as we have, in the town, a set of sewer drains running parallel with our pure hill water. The sewers of all houses must be sent into this drain, and it will be a great advantage to all persons having isolated

houses on the rivers, and to all villages, hamlets, and towns of every kind. I think the time is certainly come when we may adopt common counsel in Lancashire, and act as an united body instead of acting as a number of isolated individuals. The sewer or drain along the river will be also a reservoir of manure, that is, the sewage water may be taken out of the sewer, and put upon the land all along the river, so that it will be a mode of conveying manure in a state ready for use to a very large portion of the country, especially in the case of winding rivers, such as we have in the land lying above us. The water used for manure will then filter through the ground, and naturally will take the course of drainage water, which I propose shall, in all cases, go directly into the river, and so keep constantly adding to the amount of pure water in the river.

These drains, I think, should be very simple,—much simpler than those used for pure water, and merely brick semicircles, according as may be decided on. They might be covered with a simple covering of flat stone, unless it happens that a district is too large, and that a very large drain is needful. In any case, when these drains become full, they pass into a reservoir, and the sewage is precipitated. They then pass out pure into the river. So much confidence may be had in the liquid manure, that I believe people will be anxious to avoid the loss of any of this substance passing by them. The right to use this manure would be sold, of course, and, if obtained in this easy manner, without expense of carriage, as we may say, it will, no doubt, be most gladly used.

At any rate, I wish to explain that this provides for the manuring and draining of the land, and cleansing of the river by one and the same plan. This plan makes use of all the alkalies, ammonia, potash and soda, so that nothing put on the land is lost, and a pure water is returned to the river. I believe the banks of the rivers might, in this way, be made rich gardens. But it is certain that all the sewer water could

not be used, and it is also clear that it would not be so rich as that of Edinburgh, so that equal results could scarcely be expected. The amount not used in this manner would flow down the sewer, and would be led into the first tank or reservoir, there to be precipitated. There the solid matter would be kept, and the fluid, when clear, would proceed. There is then a constant succession of sewers for the water that has not been used on the way. Below every town and district giving off much impure water, such a depositing reservoir would be placed. Every person might then receive from the river, water for manufacturing purposes, and the making of private reservoirs, now so numerous, might be almost entirely saved. There are a few cases where fine colours are wanted, where this water might not be so well fitted as fresh water from drainage land, but these cases would be few. This would be a great saving both of land and labour, as well as water, to the country.

But not to expand too much upon it, it is then to be asked how is the precipitation to be effected.

I have mentioned that the precipitation will take place in the reservoirs, but if they are to be disinfected, so can the sewers be disinfected; it is not needful then that the precipitant be added in the reservoirs. Besides there is a difficulty in mixing the water of a reservoir, which Mr. Wrigg proposed to get over by having rails across it, allowing men to go to any part. This would, however, by no means get over the difficulty, as a man could only mix well that part which was within reach of his arm, and if the whole surface of the reservoir were covered with little whirlpools, mixing themselves in every spot, the whole mass would not thereby be mixed. I consider, therefore, that it would be of great advantage to mix in the sewer themselves; by this means the sewers would be disinfected, that great evil would be removed which we have endeavoured vainly to shut in by means of traps; some outlet, however, it will decidedly make for itself, whilst being shut

in it renders the sewers still more dangerous to clean. By disinfecting the sewers the decomposition is put a stop to during their whole course, the mixture also is being made during the flow of the water, and by the time it comes to the reservoir it will be ready to precipitate.

It has been said that this liquid will flow along the river in the manner that was proposed for removing the sewage from London, some years ago, by the painter Martin. I increase the plan simply by a succession of these. Now this liquid in its flow will form a constant supply of liquid manure, it will therefore answer the purpose of the elaborate set of tubes made by some parties for irrigation, and it may be pumped out on the surrounding ground and spread by a jet or by irrigation. It may even be drained off to a lower level, where it is convenient, and where the fall of the river is great, so as to irrigate by gravitation. This liquid being disinfected, may without fear be put upon the land without scattering around it a noisome odour. The system includes all the best portions of the other systems, in my opinion, whilst it adds new features not to be found in any hitherto devised system.

If the water were to be used by jet only, then there would be a great excess at certain portions of the year, and as it could not be properly disposed of, it must be allowed to go again into the river. This argument is, I think, almost conclusive against the mere use of the liquid manure plan; it neither uses its material, nor leaves time for consideration to the farmer, every day is bringing down its stated quantity, if it be on Christmas or Midsummer, and for good or evil this must be disposed of. If we use large precipitating tanks, we get rid of that difficulty; the matter stands until it is wanted.

But again, if we reject the liquid manure system we reject a method which has already been shewn to be of the very highest value, and more than that, we lead the liquid manure

over a great tract of country without making use of it when there, making some miles of piping in all probability without using the water except at the extremity; whereas, that long line of sewerage is itself a large and constant, as well as convenient reservoir. The same cannot be said to an equal extent of the pipes. Moreover, by disinfecting the sewer itself, we give time for the odour to be removed, taking away all fear whatever from the otherwise to be dreaded reservoir of impure water.

If this method were adopted, it is easily seen that the Irwell, the Medlock, the Irk, and the canals would at once be clean, the filthy water would not be seen, but mere condensing water would of course go back to the river. The expense of constructing a culvert, such as would convey the impure water down the river, could not be great. I am not an engineer, and cannot calculate it; but I believe, nevertheless, that it may be done cheaply and at a price which would justify its immediate commencement. The estimates for such things are generally very high, because people begin with such extravagant ideas. We see that there are many miles of sewage in this town, how many hundred I do not know, but this would be the addition of six or ten only for the immediate neighbourhood; and to begin with the Medlock, not much more than two or three. There is no need of buying land, there is land enough unbought, and the price of covering over the Medlock with such powerful arches as they are now putting upon it, would be immeasurably greater than this far more useful sewer. I would put the sewer at the side of the river, the bed is often not quite covered at one side; if sunk a little it would lie steadily, and do its work without giving any one less room or causing any one to complain.

Although this plan would act even if confined to the town, or even if confined to the Medlock, I prefer proposing it for the whole district, because there, I think, its advantages will be chiefly felt; at the same time, it is a scheme which may

be tried in pieces, so as to allow the most cautious beginning, although the first beginnings cannot well be supposed to be highly profitable. As to the mode of disinfection, it is an independent part of the subject, and although I have got much to say on that point, I am debarred by the rules of the society from bringing it forward in this place; and as I believe I have used all the time allowed by the society for reading a paper, I trust that I have given to the members a little additional material for forming a correct judgment on this great subject.

IX.—*On the Formation of Indigo-blue.* Part I.

By Edward Schunck, Ph.D., F.R.S.

[*Read April 3rd*, 1855.]

Indigo, one of the most important and extensively used dyes, owes its value entirely to a peculiar colouring matter contained in it, to which the name of *indigo-blue* or *indigotine* is applied by chemists. This substance has been repeatedly subjected to investigation, and several distinguished chemists have bestowed their attention and labour upon it. Its properties, composition and products of decomposition, have been so carefully examined, that it may safely be asserted, that there are few organic substances whose nature is more accurately known than that of indigo-blue. If, however, we inquire into the state of our knowledge regarding the origin and mode of formation of this body, it will be found that our information on this part of the subject is extremely defective. Indigo-blue may be obtained from a variety of plants, which though belonging to the most different genera and orders, are rather limited in number. It has sometimes been observed to form in the milk of cows, especially such as have been fed exclusively on saint-foin.* Latterly it has been discovered by Hassall† and others‡ in human urine, where its occurrence is attributed to a morbid

* Ann. de Chim. et de Phys., T. III., p. 269.
† Philosophical Transactions for 1854.
‡ Annalen d. Chem. u. Pharm., Bd. XC., s. 120.

tinged with a dark purple colour, forming a thin coating on the exterior. The greater proportion of the plants, however, bore leaves which did not exhibit the glaucous appearance nor the fleshy consistency which, according to authors, are characteristic of the cultivated variety of woad. They were, on the contrary, of a bright grass-green and possessed but little succulence, characters which belong rather to the wild variety.

As soon as I could collect a small quantity of leaves, I commenced my experiments. Having taken some leaves, I chopped them fine and then extracted them with boiling water. The filtered liquid was light brown and transparent, it had a bitter taste and an acid reaction. It deposited no indigo-blue, however long it might be left exposed to the atmosphere, and hence it might have been inferred that it contained no indigo-blue. Nevertheless, a very simple experiment sufficed to show that it was capable of yielding an appreciable quantity of that colouring matter. On adding to it sulphuric or muriatic acid and boiling, it became of a darker colour and deposited a quantity of dark brown, almost black flocks. Now these flocks contained indigo-blue, for if after collecting them on a filter and washing out the acid, they were treated with boiling alcohol, they communicated to the latter a bright blue colour, and on being treated with a boiling alkaline solution of protoxide of tin, they gave a yellow solution, which on exposure to the air became covered with a thin blue film. A small quantity of fresh chopped woad leaves having been pounded in a mortar with water and squeezed into a uniform green pulp, yielded on being strained through calico a dark green opaque liquor. On heating this liquor to near the boiling point the vegetable albumen contained in it coagulated, carrying down with it the green colouring matter. On now filtering through paper a green coagulum was left on the filter, while a clear light yellow liquor ran through. On adding acetic acid to the

liquid a yellow precipitate fell, and on again filtering the liquid ran through almost colourless. The lead precipitate being decomposed with dilute sulphuric acid, the filtered acid liquid was boiled, when it gave a few black flocks, which, however, contained no indigo-blue.* If, however, sulphuric or muriatic acid in excess were added to the liquid filtered from the lead precipitate, the liquid soon became green and began to deposit indigo-blue even before it could be filtered from the sulphate or chloride of lead, and after filtration and boiling it yielded flocks containing an abundance of the colouring matter. If acetate of lead was added to an extract of woad leaves made either with hot or cold water, if the precipitate thereby produced was separated by filtration and ammonia was added to the filtrate, a pale yellow precipitate fell. This precipitate having been decomposed with sulphuric acid, the filtered acid liquid gave on boiling flocks containing indigo-blue, while the flocks obtained in a similar manner by boiling with acid, the liquid filtered from this precipitate gave no indigo-blue. If this lead precipitate was treated with a cold concentrated solution of carbonate of soda, a yellow solution was obtained, which on being tried as before with sulphuric acid afforded no indigo-blue, whilst the precipitate on being treated with acid gave indigo-blue as before. But if the lead precipitate was suspended in water and a current of carbonic acid gas was passed for some time through the liquid, it was completely decomposed, its colour changed from yellow to white, and it now consisted almost entirely of carbonate of lead, whilst the liquid had acquired a yellowish colour, and on being boiled with acid deposited a quantity of blue flocks, which consisted of indigo-blue in a state of great purity, as they dissolved in boiling alcohol with a beautiful blue colour, the alcohol depositing on cooling crystalline scales, which were blue by transmitted, and

* If the acetate of lead is in the least degree contaminated with basic acetate, it will be found to precipitate some of the indigo-producing body.

acid; and that the vegetable base being thereby set at liberty combines with some colouring principle from the atmosphere, forming therewith a coloured insoluble fecula, which falls to the bottom and constitutes indigo."* Roxburgh first directed attention to the fact, that it is possible to obtain indigo by merely treating the plant with hot water, and then agitating the infusion with air, from which it follows, that fermentation is not an absolutely essential condition of the formation of indigo-blue.

Chevreul,† who was the first chemist of any eminence who examined the indigo-bearing plants and their constituents, inferred from his analyses of the *Isatis tinctoria* and *Indigofera anil*, that these plants contain indigo in the white or reduced state, in the same state in which it exists in the indigo vat; that in this state it is held in solution by the vegetable juices; and that when this solution is removed from the plant, it is converted by the action of the atmospheric oxygen into indigo-blue. The authority of so distinguished an investigator as Chevreul, has had great weight with chemists, and most persons have adopted his view without question, though it is founded chiefly on the fact of the colouring matter being deposited from a watery extract of the plant, and of the only form in which it is known to be soluble in water being that of reduced indigo.

According to Michelotti,‡ the extraction of indigo consists simply in dissolving a compound of malic acid and indigo, which is afterwards decomposed by the precipitants employed.

A few years after the appearance of Chevreul's memoirs, Giobert, Professor of Chemistry at Turin, published a work on Woad,‖ which enunciates ideas on this subject, far more nearly approaching the truth, than those either of his predecessors

* Transactions of the Society of Arts, Vol. XXVIII.

† Annales de Chimie, 1 Ser., T. LXVI., p. 5; T. LXVIII., p. 284.

‡ Journal de Physique. Avril, 1812.

‖ Traité sur le Pastel et l'Extraction de son Indigo. Paris, 1813.

or successors on the same field of investigation. The chief conclusions at which he arrived, partly by experiment and partly by reasoning, are contained in the following propositions: 1. Indigo-blue does not pre-exist in the plant, but is formed by the operations, by means of which we believe it to be extracted. 2. There exists in a small number of plants a peculiar principle, different from all the known proximate constituents of plants, and which has a tendency to be converted into indigo; this principle may be called *indigogene*. 3. This principle differs from indigo in containing an excess of carbon, of which it loses a portion in passing into the state of indigo-blue, by means of a small quantity of oxygen which it takes up. 4. The loss of this portion of carbon is caused by the latter undergoing combustion, and being converted into carbonic acid. 5. It differs in its properties from common indigo in being colourless, in being soluble in water, and by its greater combustibility, which causes it to undergo spontaneous combustion at the ordinary temperature of the atmosphere. 6. Its combustibility is enhanced by heat and by combination with alkalies, especially lime; it is diminished by the action of all acids, even carbonic acid.

About the year 1839, the *Polygonum tinctorium*, an indigo-bearing plant indigenous to China, became the subject of a series of investigations by several French chemists, chiefly in order to ascertain whether this plant, if grown in France, could be advantageously employed for the preparation of a dye to substitute foreign indigo, so as to obviate the necessity of paying such large sums to foreign nations for this article, a necessity which seems at all times to have been a subject for extreme regret in France. Baudrimont and Pelletier, after an examination of this plant, concurred in the opinion of Chevreul, that the indigo is contained in it as reduced indigo; and the latter adduced in support of this view an experiment, which consisted in treating fresh

leaves of the Polygonum with ether, taking care to exclude the air, until the green colour had changed to white, when, on exposure to the atmosphere, they speedily became blue. Robiquet,* Colin,† Turpin,‡ and Joly,‖ on the other hand, expressed a very decided conviction, that indigo-blue pre-exists in the Polygonum tinctorium, but not in a free state; that it is combined with some organic substance or substances, which render it soluble in water, ether, and alcohol; and that it requires the operation of potent agencies in order to destroy this combination and set the indigo at liberty. Osmin Hervey,§ in a memoir on the Polygonum tinctorium, which in some parts is rather obscure, inferred from his experiments: 1. That indigotine exists in the leaves of this plant in a state of combination with a resin. 2. That this natural compound of indigo and resin contains both white indigo and blue indigo, and of the latter a larger proportion the older the leaves are. 3. That by the influence of certain organic substances, the indigo-blue is again reduced to the colourless state, if the solution be effected by means of water, without any destruction of the natural compound taking place. Girardin and Preisser¶ again returned to Chevreul's view, that the colouring matter is contained in the leaves of this plant in the form of reduced indigo. Since the publication of these treatises, no new ideas have, as far as I know, been promulgated by chemists in reference to this subject.**

* Journal de Pharmacie, T. XXV., p. 62.

† Mémoire sur la Renouée des Teinturiers. Paris, 1839.

‡ Etudes microscopiques sur le gisement de la matière bleue dans les feuilles du Polygonum tinctorium, Mémoire lu à l'Académie des Sciences le 12 Novembre, 1838.

‖ Observations générales sur les plantes qui peuvent fournir des couleurs bleues à la teinture. Montpellier, 1839.

§ Journal de Pharmacie, T. XXVI., p. 290.

¶ Ibid, p. 344.

** I cannot refrain from expressing on the present occasion my regret, which is probably shared by many others, at the want of a general chemical bibli-

It will be seen that the opinions of the chemists, which I have just shortly reviewed, are of three kinds, and may be stated as follows: 1. Indigo-blue exists ready formed in the plants from which it is derived. 2. It is contained in these plants in the form of reduced indigo. 3. It does not pre-exist in the vegetable, but is formed subsequently to the extraction of the latter by means of a process of fermentation, a process which manifests itself by the evolution of gases of various kinds. To each of these views very strong objections may be raised. If the colouring matter is formed at once in the plant, it is difficult to conceive by what means it comes to be dissolved by water, for no combination of indigo-blue with any organic substance can be produced which is soluble in water. If to this it be objected, that a compound of this nature is produced by the plant and cannot after decomposition be reproduced, then it is at once admitted that indigo-blue is not contained as such within the vegetable. That it cannot exist as reduced indigo is evident, since the latter requires the presence of some alkali for its solution in water, and the juice of most, if not all, indigo-bearing plants is acid. It is difficult, moreover, to conceive how deoxidised indigo, a body having so great an affinity for oxygen, can exist in the interior of plants which we know are constantly evolving that element. That the colouring matter is formed by the process of fermentation to which the extract of the plant is subjected, as it is the oldest, so it is the most probable view. Nevertheless, the fact that indigo may be procured from plants by mere infusion with hot water and

ography, comprising references to all the known works, treatises, papers, &c. on chemical subjects written since the commencement of the modern era in chemistry. In searching for the authorities referred to in this paper, I have felt this want very sensibly. It is with some difficulty that the mere names of all the works and memoirs relating to any special branch of the science, particularly such as have fallen into oblivion, are discovered. The only attempt to supply this deficiency, and that only in regard to one department of chemistry, is Wolff's Quellenliteratur der Organischen Chemie. Halle, 1845.

precipitation with lime water, without any of the usual signs of fermentation being manifested, appears to militate against this view. On one point all authorities seem to agree, viz., that the contact with oxygen is a necessary condition of the formation, or at least precipitation of the indigo from the watery extract.*

Such being the state of our knowledge on this rather obscure department of chemical science, I resolved, though without anticipating any very decided success, to endeavour to throw a little more light on it. I was induced to do so chiefly by the following consideration. The principal vegetable colouring matters have now been discovered to be not direct products of the vital energy of plants, but products of decomposition of substances contained in the vegetable, which are themselves mostly colourless. The formation of these colouring matters takes place equally well out of the plant as within it. Indeed, it is probable that it never happens within the plant until decay has commenced, or at least until the vital energy has begun to decline. The processes of decomposition by which colouring matters are formed from other substances are of two kinds. The first consists in the absorption of oxygen and the elimination of hydrogen in the form of water; it is a process of decay (*Verwesung*. Liebig) and requires the presence not only of oxygen but of some alkali or other base. The second process is one which consists in the splitting up of the original compound into two or more simpler bodies, of which one or more are colouring matters; it is a process of fermentation, and may in general be effected as well by the action of strong acids as by that of ferments. The first process gives rise to colouring matters of a very fugitive nature, such as the colouring matters of

* Gehlen is the only chemist who, as far as I am aware, has asserted that the agitation with air in the manufacture of indigo may have for its object, not so much the oxidation as the aggregation or separation of the particles of indigo from the solution. *Vide* Schweigger's Journal, B. VI. 1812.

logwood and archil. Indeed, in this case the colouring matter, if this name be applied merely to substances endowed with a striking and positive colour, is only one of a long chain of bodies succeeding one another, and is generally not the last product of decomposition. The other process, of which the formation of alizarine is an example, yields colouring matters of a fixed and stable character, which are not further changed by a continuance of the process to which they owe their formation. Now if indigo-blue be a body which is formed from some colourless substance existing in the plant, we should infer *a priori* that the process by which it is formed is one of fermentation or putrefaction, not requiring the intervention of oxygen or of alkalies, a conclusion, however, so much at variance with the generally received ideas on the subject of the formation of indigo-blue, as to require the aid of very decisive experiments for its establishment.

I shall now proceed to give an account of the experiments which I have undertaken, with a view to elucidate this subject.

The only plant cultivated in this country which is known to yield indigo in any quantity is woad, *Isatis tinctoria*, and as it was necessary to examine the indigo-bearing plant in a fresh state and in considerable quantities, I had recourse to this one for the purpose. Having procured 10 lbs. of good French woad seed, I sowed it at the commencement of the spring of last year on about half an acre of land. It was sown in drills about two feet apart, each drill being previously well supplied with farm-yard manure. In a short time the young plants appeared, and grew vigorously during the summer months. Some of the plants bore flowers, and ripened their seeds in the course of the autumn. At no time during the whole progress of the growth were there any visible indications of the presence of blue colouring matter on the leaves or stems. Some of the ripe seeds only were

tinged with a dark purple colour, forming a thin coating on the exterior. The greater proportion of the plants, however, bore leaves which did not exhibit the glaucous appearance nor the fleshy consistency which, according to authors, are characteristic of the cultivated variety of woad. They were, on the contrary, of a bright grass-green and possessed but little succulence, characters which belong rather to the wild variety.

As soon as I could collect a small quantity of leaves, I commenced my experiments. Having taken some leaves, I chopped them fine and then extracted them with boiling water. The filtered liquid was light brown and transparent, it had a bitter taste and an acid reaction. It deposited no indigo-blue, however long it might be left exposed to the atmosphere, and hence it might have been inferred that it contained no indigo-blue. Nevertheless, a very simple experiment sufficed to show that it was capable of yielding an appreciable quantity of that colouring matter. On adding to it sulphuric or muriatic acid and boiling, it became of a darker colour and deposited a quantity of dark brown, almost black flocks. Now these flocks contained indigo-blue, for if after collecting them on a filter and washing out the acid, they were treated with boiling alcohol, they communicated to the latter a bright blue colour, and on being treated with a boiling alkaline solution of protoxide of tin, they gave a yellow solution, which on exposure to the air became covered with a thin blue film. A small quantity of finely chopped woad leaves having been pounded in a mortar with water until converted into a uniform green pulp, yielded on being strained through calico a dark green opaque liquor. On heating this liquor to near the boiling point the vegetable albumen contained in it coagulated, carrying down with it the green colouring matter. On now filtering through paper a green coagulum was left on the filter, while a clear light yellow liquid ran through. On adding acetate of lead to the

liquid a yellow precipitate fell, and on again filtering the liquid ran through almost colourless. The lead precipitate being decomposed with dilute sulphuric acid, the filtered acid liquid was boiled, when it gave a few black flocks, which, however, contained no indigo-blue.* If, however, sulphuric or muriatic acid in excess were added to the liquid filtered from the lead precipitate, the liquid soon became green and began to deposit indigo-blue even before it could be filtered from the sulphate or chloride of lead, and after filtration and boiling it yielded flocks containing an abundance of the colouring matter. If acetate of lead was added to an extract of woad leaves made either with hot or cold water, if the precipitate thereby produced was separated by filtration and ammonia was added to the filtrate, a pale yellow precipitate fell. This precipitate having been decomposed with sulphuric acid, the filtered acid liquid gave on boiling flocks containing indigo-blue, while the flocks obtained in a similar manner by boiling with acid, the liquid filtered from this precipitate gave no indigo-blue. If this lead precipitate was treated with a cold concentrated solution of carbonate of soda, a yellow solution was obtained, which on being tried as before with sulphuric acid afforded no indigo-blue, whilst the precipitate on being treated with acid gave indigo-blue as before. But if the lead precipitate was suspended in water and a current of carbonic acid gas was passed for some time through the liquid, it was completely decomposed, its colour changed from yellow to white, and it now consisted almost entirely of carbonate of lead, whilst the liquid had acquired a yellowish colour, and on being boiled with acid deposited a quantity of blue flocks, which consisted of indigo-blue in a state of great purity, as they dissolved in boiling alcohol with a beautiful blue colour, the alcohol depositing on cooling crystalline scales, which were blue by transmitted, and

* If the acetate of lead is in the least degree contaminated with basic acetate, it will be found to precipitate some of the indigo-producing body.

copper-coloured by reflected light. If instead of adding acid to any of the solutions yielding indigo-blue, caustic soda was first added in excess and the solution was left for a few moments, and then boiled with an excess of acid, it merely became brown without depositing any indigo-blue. Having taken some finely chopped woad leaves, I pounded them in a mortar with cold alcohol. On filtering I obtained a clear green solution, leaving on evaporation at a gentle heat a green syrup, from which on the addition of water a quantity of chlorophyll and fatty matter separated in drops. The watery solution, which after filtration had only a yellowish tinge, on being boiled with the addition of sulphuric acid deposited a quantity of purple flocks, which were treated, after filtration and washing with water, with successive portions of boiling alcohol. The first portions of the alcohol with which they were treated acquired a beautiful purple colour, and the last portions a pure blue, each portion depositing on standing some flocks of a fine blue colour. The green mass insoluble in water contained no indigo-blue. Having carefully dried a few woad leaves, I reduced them to powder and then treated them in a bottle with cold ether. I obtained a dark green solution, which after being filtered and evaporated spontaneously left a green syrupy residue, from which water extracted as in the preceding case a substance, which by the action of boiling sulphuric acid yielded an abundance of very pure indigo-blue.

By these and similar simple and easily performed experiments, I was enabled to infer, with positive certainty, that the Isatis tinctoria contains a substance easily soluble in hot and cold water, alcohol, and ether, which, by the action of strong mineral acids, yields indigo-blue; that the formation of the colouring matter from it can be effected without the intervention of oxygen or of alkalies, and that the latter, indeed, if allowed to act on it before the application of acid, entirely prevent the formation of colouring matter, and it

now only remained to separate it from the other constituents of the plant and ascertain its properties and composition. But, though I arrived at the conclusion just stated without any great difficulty, I found that the isolation and preparation in a state of purity of the substance whose existence had been indicated by these experiments, constituted a problem of no easy solution. I soon discovered that this body is extremely liable to decompositon, so much so, as completely to justify the assertion of an author, who in speaking of the difficulties of the manufacture of indigo, says that "nothing is more fugitive and more liable to be acted on by destructive agencies, than the colouring principle of the indigoferæ." * The continued action of water, even at a moderate, but especially at a high temperature, as well as that of alkalies, I found to induce a complete change in the body which I was endeavouring to isolate. The fact of its being completely precipitated from the watery extract of woad by means of acetate of lead and ammonia, and of the lead compound being readily decomposed by means of a current of carbonic acid gas, seemed at first to lead to an easy method of preparation. But on extracting a large quantity of the plant with cold water, adding sugar of lead to precipitate the albumen and green colouring matter, and then adding ammonia to the filtered liquid, I found that the precipitate produced by ammonia, though the alkali was not used in excess, contained the substance in an altered state. This change, the nature of which I shall treat of presently, is readily indicated by boiling some solution of the substance in water with sulphuric or muriatic acid, when it will be found that black flocks are deposited, which when treated with boiling alcohol impart to the latter no trace of blue, but a pure brown colour, a great part of the flocks remaining undissolved by the alcohol in the shape of a black powder. This change is readily effected in the watery solution, either

* Perrottet, Art de l'Indigotier, p. 110.

by the addition of alkali or by the temperature of the solution rising to any great extent above that of the atmosphere. When dissolved in alcohol or ether, on the other hand, the substance exhibits a much greater resistance to change than when dissolved in water. I, therefore, soon abandoned all idea of extracting the plant with the latter menstruum, and had recourse to alcohol and ether. I shall refrain from giving an account of the numerous experiments I made, which led to no successful issue, but shall briefly describe the three methods of preparation, which were attended with more or less advantageous results.

All three methods consist in extracting with alcohol or ether. But, before commencing, it is necessary that the plant should be thoroughly dried. The leaves alone being gathered, which should only be done when not moistened with rain or dew, are spread out in a thin layer in some warm, dry place, as, for instance, near a stove or in a drying room. All yellow or decayed leaves should be rejected. When they are perfectly dry they are carefully examined. All those leaves which during the drying have become brown, a result which takes place when the heat has been too great, are cast aside, and only those are retained which have a pale green colour. These must now be reduced to a coarse powder, an operation easily effected if the leaves be taken while still warm, as they are then quite brittle, whereas if allowed to remain exposed to the atmosphere they attract moisture again, and become flaccid and difficult to pulverize. The powder must be kept warm until it is used.

I. The leaves thus reduced to powder being put in a displacement apparatus, such as is used for the preparation of tannic acid, are extracted with cold alcohol. The percolating liquid is dark green. The extraction is continued until the liquid runs through of a light green colour. The alcoholic extract is now distilled in a retort, until a great part

of the alcohol has passed over. It is then evaporated in a basin at a moderate temperature. During evaporation a large quantity of chlorophyll and fatty matter separates as a green glutinous mass, which is to be separated by filtration. The filtered liquid, which is brown, is to be further evaporated until it leaves a thick brown syrup. This syrup being poured into a flask is redissolved in warm alcohol, which it does with some difficulty on account of the change which the substance has undergone in consequence of the heat employed in distilling the alcohol. To the warm solution there is now added several times its volume of ether. The ether renders the solution milky and precipitates a large quantity of matter, which collects at the bottom of the flask into a dark brown syrup. After this syrup has completely settled, the ether, which is also dark brown, is distilled. When the greatest part has distilled over, water is added to the syrupy residue. A quantity of brown fatty matter is precipitated, which is filtered. The filtered liquid is light yellow, and contains the substance almost in a state of purity. Should a further purification, however, be necessary, this is best effected by agitating the liquid in the cold with hydrated oxide of copper. A green solution is obtained which is filtered, and a current of sulphuretted hydrogen gas being passed through it, it is again filtered from the precipitated sulphuret of copper, and evaporated either spontaneously or in vacuo over sulphuric acid. This method is attended with considerable loss, as the whole of the brown syrup insoluble in ether, the quantity of which is not trifling, is formed at the expense of the indigo-producing body.

II. The second method consists in simply extracting the pounded woad leaves with ether in a displacement apparatus; distilling the greatest part of the ether; evaporating the remaining green liquid at a moderate temperature; adding a little cold water to the syrupy residue; separating the insoluble chlorophyll and other matters by filtration and

evaporating the yellow liquid as before, either spontaneously in the air or in vacuo. If purification should be necessary, it is effected, as in the preceding case, by means of oxide of copper. I endeavoured to modify this method by agitating the etherial extract with cold water, but without any advantage resulting, as the substance was not entirely removed from the ether by means of water, a considerable quantity still remaining dissolved in the ether.

III. The pounded woad leaves are extracted in a displacement apparatus as before with cold alcohol. To the green alcoholic extract there is added an alcoholic solution of acetate of lead, which produces a pale green precipitate, the precipitation being then completed by the addition of a little ammonia. The precipitate which is bulky is placed on a filter and washed with cold alcohol, until the percolating liquid instead of being dark green is only light green, and the excess of acetate of lead and ammonia have been removed. It is then suspended in water and a current of carbonic acid gas is passed through the liquid. The precipitate gradually becomes paler in colour and at last almost white, and loses considerably in bulk, while the liquid acquires a yellow colour. The latter being filtered, sulphuretted hydrogen is passed through it to precipitate a little oxide of lead contained in it, and being again filtered is evaporated as before either in the air or in vacuo over sulphuric acid.

Of these three methods I prefer the last, as being more expeditious than the first and less costly than the second. One precaution must not be forgotten, that of never in the last instance attempting to evaporate the solution at a higher temperature than the ordinary one. If the attempt be made, the substance will undergo an entire change, as I have repeatedly discovered to my cost. This change consists in the substance taking up the elements of water. It takes place as well in vacuo as in the air. I have no reason to

believe that the oxygen of the atmosphere has any influence in producing decomposition, at least at the usual temperature, and though I have generally in the last instance evaporated in vacuo, I think the evaporation may just as well be conducted in the air. Notwithstanding all precautions, however, it is difficult to avoid some portion of the substance becoming changed during evaporation.

The body, the preparation of which I have just described, I propose to call *Indican*.* By evaporation of its watery solution it is obtained in the form of a yellow transparent glutinous residue, which can only be rendered dry by spreading it out in thin layers and leaving it for some time in vacuo over sulphuric acid. On attempting to dry it in the waterbath, it immediately undergoes a complete alteration. Its taste is slightly bitter and nauseous. Its solutions have always an acid reaction, but whether this reaction is peculiar to it in an absolutely pure state, I am unable to say. When heated in a tube it swells up and gives fumes which condense to a brown oily sublimate, in which after some time a white crystalline substance is formed. When boiled with caustic alkali it evolves ammonia. Its compounds have a yellow colour. With caustic alkalies, baryta, and lime water, the watery solution turns of a bright yellow. The alcoholic solution gives with sugar of lead a bright sulphur-yellow precipitate, which is increased by the addition of ammonia. The watery solution gives no precipitate with acetate of lead, until ammonia is also added. Its most remarkable and interesting property, is that of yielding indigo-blue when

* As the termination *an* has not yet been applied by chemists to designate any peculiar class of bodies, I propose to restrict it to the names of such substances of a complex constitution, like rubian, as are direct products of the vital energy of plants or animals, and which by their decomposition give rise to one or more series of organic compounds of a simpler constitution. In applying it, it will of course be necessary, carefully to ascertain, that the substance to be named is really a proximate constituent of some organism and not itself the result of any process of decomposition either within or out of the organism, that it is an educt and not a product.

treated with strong acids. If sulphuric or muriatic acid be added to its watery solution, no change whatever is perceptible for some time. But on heating to near the boiling point, the solution immediately becomes sky-blue. On boiling for a short time, the solution becomes opalescent. On continuing to boil it acquires a purple colour, and then, provided the solution is tolerably concentrated, a copious deposit consisting of dark purplish-blue flocks is formed. The liquid filtered from these flocks retains a yellow colour and contains a peculiar species of sugar, to which I shall return presently. The flocks themselves do not consist of indigo-blue only. After being collected on a filter and washed with water they appear of a dark purple colour, the filter also acquiring during washing a purple tinge. If they be now treated with alcohol, a part dissolves even in the cold, but to a greater extent on heating, the alcohol acquiring a beautiful purple colour. If the flocks remaining undissolved be treated after filtration with an additional quantity of boiling alcohol, the latter acquires a more blueish tinge. Each succeeding portion of alcohol with which the flocks are boiled acquires more and more of a blue colour, until at last the colour is a pure indigo-blue. There remains in general a large quantity of indigo-blue undissolved, and the alcoholic liquids on standing deposit the colouring matter contained in them in the shape of bright blue flocks. The purple alcoholic solution leaves on evaporation a reddish-brown residue, which bears the greatest resemblance to, if it is not identical with, the indigo-red of Berzelius. Like the latter substance it is quite insoluble in caustic alkalies, and gives when heated in a tube purple fumes and a small quantity of a white crystalline sublimate. I propose to call this substance *Indirubine*. I have found that it is invariably formed along with indigo-blue whenever indican is decomposed by acids. Nevertheless, the quantity of indigo-blue produced is always relatively larger when the indican is pure, than

when the latter has begun to change. Of the two colouring matters, the indigo-blue is always the first to be formed. If sulphuric or muriatic acid be added to a solution of indican in the cold, and the mixture be allowed to stand in the cold for some time, a slight precipitate is gradually deposited which consists almost entirely of indigo-blue. It is only after boiling for some time that the formation of indirubine commences, when the colour of the liquid changes from blue to purple. The constant occurrence of a red colouring matter both in indigo and in the indigo-bearing plants along with indigo-blue, a fact which has been repeatedly observed, has led chemists to suspect that there must be some necessary connection between the two. From the experiments just described, it follows that in the case of woad at least they are both products of decomposition of one substance. If nitric acid be added to a watery solution of indican, a slight deposit of indigo-blue is formed, which of course disappears immediately on heating the liquid.

There is another very remarkable property of indican, which I have to describe, a property, the knowledge of which will probably throw great light on the process of manufacturing indigo. If indican in the form of syrup, as obtained by evaporation of the watery solution, be heated for some time in the waterbath, or if its watery solution be boiled, or even moderately heated, it undergoes a complete metamorphosis. If the solution be now evaporated it leaves a yellow syrupy residue, not to be distinguished in appearance from indican itself. It will be found, however, to have become insoluble in ether, and not easily soluble in alcohol. If ether be added to its solution in alcohol, the solution becomes milky and deposits oily drops which collect at the bottom of the vessel to a yellow or brown syrup, the unchanged indican, if there be any present, remaining dissolved in the ether. In its other outward properties, it has not undergone any marked change. In the next stage of the

process the indican acquires a brown colour and becomes quite insoluble in cold alcohol, but it still dissolves, though with difficulty, in boiling alcohol. By continuing the process the substance acquires a dark brown colour, and its watery solution now gives a copious precipitate with acetate of lead. As soon as the indican has entered even on the first stage of this process of change, it ceases to give the least trace of indigo-blue with acids. A short period occurs at the commencement of the process, during which the watery solution when boiled with sulphuric acid deposits purple flocks consisting of indirubine only. Afterwards, however, it yields other products, which are always the same at every subsequent stage of the process. If the watery solution be then boiled with the addition of sulphuric or muriatic acid, it becomes in the first instance of a darker colour, and after considerable boiling deposits slowly a quantity of dark brown, almost black flocks. The liquid filtered from these flocks contains sugar, just as in the case of indican itself. The flocks themselves generally consist of two bodies. If they be collected on a filter, washed with water and then treated with boiling alcohol, a part dissolves with a brown colour, and after filtration and evaporation is left as a dark brown shining resinous substance. This substance melts in boiling water into brown coherent masses. It is completely dissolved and decomposed by boiling nitric acid. It dissolves in ammonia with a brown colour, and the solution gives brown precipitates with the chlorides of barium and calcium. It is completely precipitated from its alcoholic solution by sugar of lead, the precipitate being brown. I propose to call this body *Indiretine*. That portion of the dark brown flocks which is insoluble in boiling alcohol, dissolves in caustic alkalies with a dark brown colour, and is precipitated by acids in black flocks. As it bears some resemblance in its outward properties to humus, I shall call it

Indihumine. Its similarity to the indigo-brown of Berzelius is so great, as almost to lead me to suspect that it is the same body. Whether this is the case or not, can only be ascertained by analysis. Sometimes the brown substance formed by the action of acids on modified indican is entirely soluble in boiling alcohol and contains no indihumine, but under what conditions this takes place, I am unable to say. The change which indican undergoes during this process consists merely in its absorbing the elements of water. It proceeds in vacuo as well as in the air, provided the temperature be raised to a certain degree, which proves that oxygen plays no part in the process. It is apparently effected instantly when indican comes into contact with alkalies in its watery solution, though the alcoholic solution may be made alkaline, with ammonia at least, without any alteration taking place. It is certainly a most remarkable circumstance, that by merely taking up the elements of water indican should be converted into a substance, which when exposed to the action of acids yields no longer indigo-blue and its allied red colouring matter, but bodies of an entirely distinct nature which have none of the properties of colouring matters, and it goes far to prove that indigo-blue does not pre-exist in indican even as a copula, but is merely contained in it potentially. That the view I have taken of this metamorphosis is the correct one, is proved by a singular observation which I once accidentally made. Having on one occasion obtained a dilute solution of indican, I tried a small quantity of it by boiling with sulphuric acid, and ascertained that it gave indigo-blue and indirubine. But on heating the whole quantity to the boiling point with acid, I obtained instead of these two bodies a substance dissolving in alcohol with a brown colour. It was evident that the indican, in consequence probably of the solution being very dilute, had taken up the elements of water before the acid

could act on it, and that the latter then gave rise to the products of decomposition peculiar to the hydrate. In general, however, the nature of the flocks which are deposited on boiling a watery solution of indican with sulphuric or muriatic acid affords a very good test of the purity of the indican. A solution is boiled in a test tube partly filled, and the flocks which are formed collected on a filter, washed with water, and then treated with successive portions of boiling alcohol until no more will dissolve. If to the first portions of alcohol a purple colour be imparted, and a fine purplish-blue to the succeeding ones, then the indican may be considered pure. If the colour of the alcohol is brown, and if black flocks are left undissolved, the substance has undergone a complete change.

The sugar which is formed when acids act either on indican or its hydrates, is obtained in a state of purity in the following manner. If sulphuric acid be employed, which is preferable to muriatic, the acid liquid is filtered from the flocks consisting of indigo-blue and other products of decomposition, and the acid is removed by means of an excess of acetate of lead. If to the liquid filtered from the sulphate of lead, an excess of ammonia is added, the sugar is precipitated in combination with oxide of lead. The precipitate, which is usually yellow and bulky, is after washing decomposed with sulphuretted hydrogen, and from the liquid filtered from the sulphuret of lead the sugar is again precipitated with acetate of lead and ammonia. The second precipitate which is usually almost white is again decomposed with sulphuretted hydrogen, and the filtered liquid is evaporated over sulphuric acid, when it leaves a colourless or only slightly yellow syrup, which has the following properties. It has a faintly sweet taste. When heated it swells up emitting the usual smell of burning sugar, and then burns leaving much charcoal. With concentrated sulphuric

acid it strikes a dark red colour, which on heating becomes black. Boiling nitric acid decomposes it with an evolution of nitrous fumes. When its watery solution is boiled with caustic soda it becomes yellow and deposits a few brown flocks. With sulphate of copper and caustic soda it gives a blue solution, which on boiling becomes yellow and then deposits suboxide of copper. If nitrate of silver be added to its watery solution, while boiling, a little metallic silver is precipitated, and when ammonia is added a further reduction takes place, accompanied by the formation of a metallic mirror. On adding chloride of gold to the watery solution and boiling, a quantity of metallic gold is deposited in bright scales and spangles; and on adding caustic alkali to the filtered solution an additional quantity of gold is precipitated as a purple powder. The watery solution gives no precipitates either with neutral or basic acetate of lead, only on adding ammonia does any precipitation take place. It is soluble in alcohol, but not in ether. In its outward properties, therefore, this sugar does not differ in any marked degree from other kinds of sugar obtained by the decomposition of complex organic bodies, such as that derived from rubian. In its composition, however, it differs essentially from other species of sugar, as I shall presently show.

I have hitherto been unable, I regret to say, to ascertain the exact composition of indican by direct experiment. On account of its deliquescent nature, and its so readily undergoing change when heated, it was impossible to subject it to analysis in a free state; and I was, therefore, obliged to have recourse to the lead compound. But when this compound is precipitated from a watery solution by means of acetate of lead and ammonia, it no longer contains unchanged indican, but one of the bodies formed by the combination of the latter with water. It is necessary, however, to use water in some stage of the preparation, for if the lead

compound be precipitated from an alcoholic extract of woad with acetate of lead and ammonia, if the precipitate be decomposed, after washing with alcohol, by suspending it in alcohol and passing a stream of carbonic acid through the liquid, and the substance be again precipitated from the filtered liquid by means of acetate of lead and ammonia, the lead compound thus formed will be found to contain besides indican a quantity of fatty matter, from which the indican can only be separated by means of water, and its analysis leads, as I have ascertained, to no satisfactory results. It is, therefore, necessary to evaporate a watery solution of indican spontaneously, to dissolve the residue in alcohol, and precipitate with acetate of lead and ammonia, taking care to leave a slight excess of indican in solution. The following analysis was made with a specimen of the lead compound prepared in this manner, the indican itself having been obtained by the third method described above.

I. 1.4340 grm. of the compound dried in vacuo and burnt with oxide of copper and chlorate of potash gave 0.9600 grm. carbonic acid and 0.2860 water.

1.2170 grm. gave 0.1700 grm. chloride of platinum and ammonium.

0.3790 grm. gave 0.3080 grm. sulphate of lead.

These numbers lead to the following composition:—

	Eqs.		Calculated.	Found.
Carbon.....	52	312	18.67	18.25
Hydrogen	35	35	2.09	2.21
Nitrogen	1	14	0.83	0.87
Oxygen	38	304	18.23	18.88
Oxide of Lead.....	9	1005.3	60.18	59.79
		1670.3	100.00	100.00

Notwithstanding the care, however, which I took in the

preparation of this specimen, I found that it did not contain unchanged indican, as a little of it when tested with sulphuric acid gave no indigo-blue. It is, nevertheless, the purest specimen of the lead compound which I have analyzed; that is to say, the substance combined with the oxide of lead contained the least amount of hydrogen and oxygen.

The next analysis which I shall give, places in a striking light the effect which alkalies exert on indican. I took some of the same solution of indican which I had employed for the preceding analysis, and which I found to give, when a little of it was boiled with acid, very pure indigo-blue; but instead of evaporating it I added a large quantity of alcohol to it, and then precipitated with acetate of lead and ammonia. The precipitate no longer contained unchanged indican, and the substance combined with the oxide of lead differed in composition from that of the preceding analysis, by containing the elements of two equivalents more of water. The third analysis was performed with a lead compound made in the same way as that of the first analysis, but from a specimen of indican prepared by the first method. The composition I found to be exactly the same as that of the compound of the second analysis.

II. 1.0960 grm. dried in vacuo and burnt with oxide of copper and chlorate of potash gave 0.7060 grm. carbonic acid and 0.2020 water.

1.5600 grm. gave 0.1880 grm. chloride of platinum and ammonium.

0.8930 grm. gave 0.7520 grm. sulphate of lead.

III. 1.1000 grm. gave 0.7135 grm. carbonic acid and 0.2050 water.

1.8350 grm. gave 0.2260 grm. chloride of platinum and ammonium.

0.5710 grm. gave 0.4770 grm. sulphate of lead.

From these numbers I deduced the following composition:—

	Eqs.		Calculated.	II.	III.
Carbon.....	52	312	17.33	17.56	17.69
Hydrogen	37	37	2.05	2.04	2.07
Nitrogen	1	14	0.77	0.75	0.77
Oxygen	40	320	17.80	17.69	18.01
Oxide of Lead...	10	1117	62.05	61.96	61.46
		1800	100.00	100.00	100.00

After deducting the oxide of lead, the amount of which is unusually large for a compound of definite constitution, the organic substance combined with it has the following composition:—

	Eqs.		Calculated.	II.	III.
Carbon.....	52	312	45.68	46.16	45.90
Hydrogen	37	37	5.41	5.36	5.37
Nitrogen	1	14	2.04	1.97	1.99
Oxygen	40	320	46.87	46.51	46.74
		683	100.00	100.00	100.00

An analysis which I made of a lead compound, prepared directly from a watery extract of woad by precipitating with acetate of lead, filtering and then adding ammonia to the filtered liquid, gave a composition agreeing pretty well with the formula $C_{52}\ H_{43}\ NO_{46} + 13\ PbO$.

It appears, therefore, that the organic substances contained in these lead compounds differ from one another merely by the elements of water; and it may hence be inferred, with a great degree of probability, that indican itself in a state of purity differs in composition from them merely by containing the elements of several equivalents of water less. Assuming its composition to be represented by the formula $C_{52}\ H_{33}\ NO_{36}$, it must be shown how this formula explains the formation of indigo-blue. Before this can be

done, however, it is necessary to know the composition of the sugar which is always formed simultaneously with the indigo-blue. The lead compound of the sugar prepared as above described, and dried in vacuo, was analyzed with the following results:—

I. 1.0580 grm. burnt with chromate of lead gave 0.4550 grm. carbonic acid and 0.1670 water.

0.7620 grm. gave 0.7490 grm. sulphate of lead.

II. 1.0960 grm. after being dried in vacuo for some time longer gave 0.4740 grm. carbonic acid and 0.1640 water.

0.6420 grm. gave 0.6370 grm. sulphate of lead.

These numbers lead to the following composition:—

	Eqs.		Calculated.	I.	II.
Carbon.....	12	72	11.69	11.72	11.79
Hydrogen	9	9	1.46	1.75	1.66
Oxygen	11	88	14.30	14.21	13.55
Oxide of Lead...	4	446.8	72.55	72.32	73.00
		615.8	100.00	100.00	100.00

If the formula of the lead compound is $C_{12} H_9 O_{11} + 4 PbO$, it is probable that the sugar in an uncombined state has the formula $C_{12} H_{10} O_{12}$. It differs, therefore, from other kinds of sugar by containing less hydrogen than is necessary to form water with the oxygen. Its formula is, however, perfectly in accordance with the one which I have adopted for indican, viz., $C_{52} H_{33} NO_{36}$. If we suppose the latter to take up two equivalents of water, it will then simply split up into 1 equivalent of indigo-blue and 3 equivalents of sugar, as will be seen by the following equation:—

1 eq. Indican $C_{52} H_{33} NO_{36}$
2 eqs. Water $H_2 O_2$
$C_{52} H_{35} NO_{38}$

$=$

$C_{16} H_5 NO_2$ 1 eq. Indigo-blue
$C_{36} H_{30} O_{36}$ 3 eqs. Sugar.
$C_{52} H_{35} NO_{38}$

I assume that the composition of the blue colouring matter derived from indican is the same as that of indigo-blue, since

an examination of the properties of the former leaves little doubt concerning their identity. I regret not having as yet been able to ascertain by analysis, whether this is the case or not, as I have devoted the whole of the material at my disposal to an investigation of the properties and composition of indican itself.

I also assume that indican in undergoing decomposition with acids splits up immediately into 1 equivalent of indigo-blue and 3 equivalents of sugar. It is, however, possible that these three equivalents of sugar may not be eliminated all at once; and from one analysis which I made, I should conclude that they separated successively. Having extracted some dried woad leaves with cold ether, I poured the etherial extract into a large bottle, and agitated it with about half its volume of cold water. The ether was poured off, and the watery liquid was employed again for agitation with several successive portions of etherial extract of woad. It acquired at last a dark yellow colour. The ether contained in it was removed by spontaneous evaporation, and it was then evaporated under a bell over sulphuric acid. At first it yielded indigo-blue when boiled with sulphuric acid; but the evaporation having been conducted in too warm a place, the indican contained in it became changed, and it ceased to give blue flocks with acids. After the evaporation was completed there was left a brown syrupy residue, which was redissolved in alcohol. Acetate of lead produced in the alcoholic solution a cream-coloured precipitate which was separated by filtration, and on adding a small quantity of ammonia to the filtered liquid, a cream-coloured precipitate again fell, which was collected on a filter, washed with alcohol, and dried in vacuo. On analyzing it I obtained the following results:—

0.3705 grm. burnt with oxide of copper and chlorate of potash gave 0.2670 grm. carbonic acid and 0.0730 water.

0.3800 grm. gave 0.0680 grm. chloride of platinum and ammonium.

0.2680 grm, gave 0.2160 grm. sulphate of lead.

In 100 parts it contained, therefore,

Carbon	19.65
Hydrogen	2.18
Nitrogen	1.12
Oxygen	17.75
Oxide of Lead	59.30
	100.00

After deducting the oxide of lead, the amount of which stands in no simple relation to that of the other constituents, the organic substance combined with the oxide of lead will be found to have a composition expressed by the formula $C_{40}\ H_{26}\ NO_{27}$, as will be seen by the following calculation:—

	Eqs.		Calculated.	Found.
Carbon	40	240	48.38	48.28
Hydrogen	26	26	5.24	5.35
Nitrogen	1	14	2.82	2.75
Oxygen	27	216	43.56	43.62
		496	100.00	100.00

This body is, therefore, formed from indican by the latter taking up 3 equivalents of water and then losing 1 equivalent of sugar, as will be evident from the following equation:—

$$\left.\begin{array}{l}\text{1 eq. Indican } C_{52}H_{33}NO_{36}\\ \text{3 eqs. Water } \quad H_3 \quad O_3\end{array}\right\} = \left\{\begin{array}{l}C_{40}H_{26}NO_{27}\\ C_{12}H_{10}\quad O_{12}\end{array}\right. \text{1 eq. Sugar.}$$

$$C_{52}H_{36}NO_{39} \qquad C_{52}H_{36}NO_{39}$$

It is perfectly conceivable that an additional equivalent of sugar may separate from the body $C_{40}\ H_{26}\ NO_{27}$ before the

decomposition is finally completed; that is to say, that there exists another intermediate body containing 28 equivalents of carbon.

Of the red colouring matter, which I have called indirubine, I have not yet obtained a sufficient quantity for analysis.

I have several times submitted indihumine, obtained on different occasions, to analysis, but without being able to arrive at any positive conclusion regarding its composition. The difficulty of doing so arises from the circumstance of this substance forming compounds with alkalies and other bases which are not completely decomposed by acids. The analyses which I have made agree best with the formula $C_{16}\ H_8\ NO_5$. If this be the correct formula, it differs in composition from indigo-blue by the elements of three equivalents of water, just as the body or bodies from which it is formed differ from indican by containing the elements of several equivalents more water.

The analyses of indiretine led to more definite results. The substance was prepared from indican, which had undergone the alteration of which I have several times spoken, by treating it with boiling sulphuric acid, collecting the dark brown deposit which was formed, on a filter, washing out the acid, treating with boiling alcohol, filtering from the indihumine which remained undissolved, and evaporating the alcoholic solution to dryness.

I. 0.4420 grm. dried in the waterbath and burnt with oxide of copper and chlorate of potash gave 0.9930 grm. carbonic acid and 0.2100 water.

0.5470 grm. gave 0.3415 grm. chloride of platinum and ammonium.

II. 0.5370 grm. of another preparation gave 1.2130 grm. carbonic acid and 0.2675 water.

0.8780 grm. gave 0.4320 grm. chloride of platinum and ammonium.

III. 0.2760 grm. of a third preparation gave 0.6190 grm. carbonic acid and 0.1420 water.

These numbers correspond with the following composition:—

	Eqs.	Calculated.	I.	II.	III.
Carbon... 36	216	61.02	61.27	61.60	61.16
Hydrogen 20	20	5.64	5.27	5.53	5.71
Nitrogen.. 1	14	3.95	3.92	3.09	
Oxygen... 13	104	29.39	29.54	29.78	
	354	100.00	100.00	100.00	

Assuming $C_{36}\ H_{20}\ NO_{13}$ to be the correct formula for indiretine, then the formation of this substance from indican, or rather from its hydrates, can only be explained by supposing that carbonic acid is evolved during the process. If we take, for instance, the substance represented by the formula $C_{52}\ H_{37}\ NO_{40}$, which gives indiretine when treated with acids, we may suppose it to split up into 1 equivalent of indiretine, 1 equivalent of sugar, 4 equivalents of carbonic acid, and 7 equivalents of water, as will be seen by the following equation:—

$$C_{52}\ H_{37}\ NO_{40} = \begin{cases} C_{36}\ H_{20}\ NO_{13} & 1 \text{ eq. Indiretine.} \\ C_{12}\ H_{10}\ O_{12} & 1 \text{ eq. Sugar.} \\ C_{4}\ \ \ O_{8} & 4 \text{ eqs. Carbonic Acid.} \\ H_{7}\ O_{7} & 7 \text{ eqs. Water.} \end{cases}$$

$$C_{52}\ H_{37}\ NO_{40}$$

I have certainly not observed the disengagement of carbonic acid during the formation of indiretine, but the evolution of gas might easily elude observation during the long-continued boiling, which is necessary for the production of this substance.

The want of material has, for the present, interrupted the further prosecution of my experiments. As soon as I shall have obtained an additional quantity of the fresh plant, it is

my intention to continue them. The action of acids on indican requires still further examination, and the effects produced by ferments and other agents remain to be investigated. I also propose to examine other indigo-bearing plants, in order to ascertain whether they contain indican or not.

The results of the present investigation may be summed up in the following propositions:—

1. The Isatis tinctoria does not contain indigo-blue ready formed, either in the blue or colourless state.

2. The formation of the blue colouring matter in watery extracts of the plant is neither caused, nor promoted by, the action of oxygen or of alkalies.

3. Indigo-blue cannot be said to exist in any state of combination in the juices of the plant, it is merely contained in them potentially.

X.—*On the Permian Beds of the North-West of England.*

By Edward W. Binney, F.G.S.

[*Read March 20th*, 1855.]

My observations on these strata will be confined to such sections as I have met with in the counties of Lancaster, Chester, Cumberland, Westmoreland, and York.

The permian beds, as is well known, constitute the highest portion of the palæozoic rocks, comprising that part of the earth's crust which lies between the carboniferous formation and the trias, and were first named by Sir Roderick Impey Murchison after a province in Russia, Perm, where they are met with on a grand scale. Long before the date of Sir Roderick's work on Russia, however, Professor Sedgwick had most ably and carefully described these deposits, and shewn their true relation to the underlying carboniferous and overlying new red sandstone groups, in his admirable paper on the Magnesian Limestone of the North of England, published in vol. III. (2nd series) of the Transactions of the Geological Society. The same author has also contributed other valuable information on the permian beds of the north-west of England, contained in several papers published by the Geological Society.*

* See vol. IV. (2nd series) of the Transactions of the Geological Society of London, and vol. VIII., page 36, of the same society's Quarterly Journal.

could act on it, and that the latter then gave rise to the products of decomposition peculiar to the hydrate. In general, however, the nature of the flocks which are deposited on boiling a watery solution of indican with sulphuric or muriatic acid affords a very good test of the purity of the indican. A solution is boiled in a test tube partly filled, and the flocks which are formed collected on a filter, washed with water, and then treated with successive portions of boiling alcohol until no more will dissolve. If to the first portions of alcohol a purple colour be imparted, and a fine purplish-blue to the succeeding ones, then the indican may be considered pure. If the colour of the alcohol is brown, and if black flocks are left undissolved, the substance has undergone a complete change.

The sugar which is formed when acids act either on indican or its hydrates, is obtained in a state of purity in the following manner. If sulphuric acid be employed, which is preferable to muriatic, the acid liquid is filtered from the flocks consisting of indigo-blue and other products of decomposition, and the acid is removed by means of an excess of acetate of lead. If to the liquid filtered from the sulphate of lead, an excess of ammonia is added, the sugar is precipitated in combination with oxide of lead. The precipitate, which is usually yellow and bulky, is after washing decomposed with sulphuretted hydrogen, and from the liquid filtered from the sulphuret of lead the sugar is again precipitated with acetate of lead and ammonia. The second precipitate which is usually almost white is again decomposed with sulphuretted hydrogen, and the filtered liquid is evaporated over sulphuric acid, when it leaves a colourless or only slightly yellow syrup, which has the following properties. It has a faintly sweet taste. When heated it swells up emitting the usual smell of burning sugar, and then burns leaving much charcoal. With concentrated sulphuric

acid it strikes a dark red colour, which on heating becomes black. Boiling nitric acid decomposes it with an evolution of nitrous fumes. When its watery solution is boiled with caustic soda it becomes yellow and deposits a few brown flocks. With sulphate of copper and caustic soda it gives a blue solution, which on boiling becomes yellow and then deposits suboxide of copper. If nitrate of silver be added to its watery solution, while boiling, a little metallic silver is precipitated, and when ammonia is added a further reduction takes place, accompanied by the formation of a metallic mirror. On adding chloride of gold to the watery solution and boiling, a quantity of metallic gold is deposited in bright scales and spangles; and on adding caustic alkali to the filtered solution an additional quantity of gold is precipitated as a purple powder. The watery solution gives no precipitates either with neutral or basic acetate of lead, only on adding ammonia does any precipitation take place. It is soluble in alcohol, but not in ether. In its outward properties, therefore, this sugar does not differ in any marked degree from other kinds of sugar obtained by the decomposition of complex organic bodies, such as that derived from rubian. In its composition, however, it differs essentially from other species of sugar, as I shall presently show.

I have hitherto been unable, I regret to say, to ascertain the exact composition of indican by direct experiment. On account of its deliquescent nature, and its so readily undergoing change when heated, it was impossible to subject it to analysis in a free state; and I was, therefore, obliged to have recourse to the lead compound. But when this compound is precipitated from a watery solution by means of acetate of lead and ammonia, it no longer contains unchanged indican, but one of the bodies formed by the combination of the latter with water. It is necessary, however, to use water in some stage of the preparation, for if the lead

compound be precipitated from an alcoholic extract of woad with acetate of lead and ammonia, if the precipitate be decomposed, after washing with alcohol, by suspending it in alcohol and passing a stream of carbonic acid through the liquid, and the substance be again precipitated from the filtered liquid by means of acetate of lead and ammonia, the lead compound thus formed will be found to contain besides indican a quantity of fatty matter, from which the indican can only be separated by means of water, and its analysis leads, as I have ascertained, to no satisfactory results. It is, therefore, necessary to evaporate a watery solution of indican spontaneously, to dissolve the residue in alcohol, and precipitate with acetate of lead and ammonia, taking care to leave a slight excess of indican in solution. The following analysis was made with a specimen of the lead compound prepared in this manner, the indican itself having been obtained by the third method described above.

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Notwithstanding the care, however, which I took in the

preparation of this specimen, I found that it did not contain unchanged indican, as a little of it when tested with sulphuric acid gave no indigo-blue. It is, nevertheless, the purest specimen of the lead compound which I have analyzed; that is to say, the substance combined with the oxide of lead contained the least amount of hydrogen and oxygen.

The next analysis which I shall give, places in a striking light the effect which alkalies exert on indican. I took some of the same solution of indican which I had employed for the preceding analysis, and which I found to give, when a little of it was boiled with acid, very pure indigo-blue; but instead of evaporating it I added a large quantity of alcohol to it, and then precipitated with acetate of lead and ammonia. The precipitate no longer contained unchanged indican, and the substance combined with the oxide of lead differed in composition from that of the preceding analysis, by containing the elements of two equivalents more of water. The third analysis was performed with a lead compound made in the same way as that of the first analysis, but from a specimen of indican prepared by the first method. The composition I found to be exactly the same as that of the compound of the second analysis.

II. 1.0960 grm. dried in vacuo and burnt with oxide of copper and chlorate of potash gave 0.7060 grm. carbonic acid and 0.2020 water.

1.5600 grm. gave 0.1880 grm. chloride of platinum and ammonium.

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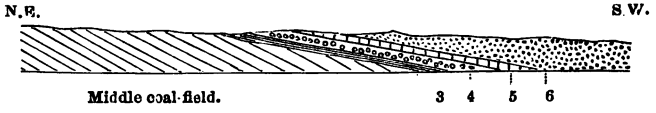
III. 1.1000 grm. gave 0.7135 grm. carbonic acid and 0.2050 water.

1.8350 grm. gave 0.2260 grm. chloride of platinum and ammonium.

0.5710 grm. gave 0.4770 grm. sulphate of lead.

No fossils have as yet been met with in these deposits, except the small lenticular markings, but the position and character of the beds lead me to class them with the lower part of the magnesian limestone, and its underlying bed of conglomerate.

NORBURY SECTION.*



Little evidence of the relation which exists between the coal-measures and the new red sandstone strata is to be met with in the country lying betwixt Rushton Spencer and Stockport, the drift deposits so enveloping the district as to prevent the beds from being seen. In the brook-course at Norbury, near the mill, about three miles south of Stockport, there was a good section a few years ago, but it has been since covered up. It consisted of the following beds, in the descending order:—

	ft.	in.
Upper new red sandstone	0	0
Red clays	6	0
Soft sandstone of a conglomerate character, and a brownish red colour	5	3
Red clays	12	0
Coal-measures (middle part of the field)	0	0
	23	3

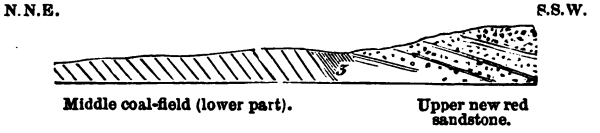
The upper new red sandstone dipped to the south-west, at angles varying from 10 to 20°. The red beds which I take to be permian, dipped to the south-west, at an angle of 20°, and the coal-measures had an inclination in the same direction,

* For the loan of this and eight other of the wood cuts, used to illustrate this memoir, I am indebted to the Council of the London Geological Society.

at an angle of 40°. No fossils were found in any of the beds. The bed of soft sandstone is evidently the same deposit as that seen in the Cheetham Weir Hole, and hereinafter mentioned in the Collyhurst section.

This section (Norbury) appears to shew that the red marls with limestones, as seen at Collyhurst, are not conformable to the overlying upper new red sandstone, or they would most probably have been seen; it also proves that the conglomerate bed is unconformable to the lower new red sandstone of Heaton Mersey and Collyhurst. No doubt the last-named deposit is variable in thickness, but we can scarcely suppose that a rock of between four and five hundred feet thick, at least, can, in the distance of three miles, dwindle down into the sandy conglomerate of five feet.

Fog Brook Section.

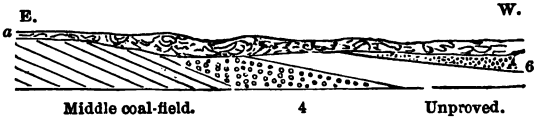


This is seen in the little stream known by the name of Fog Brook, in Offerton, about three miles south-east of Stockport. In it the upper new red sandstone appears well developed, dipping at an angle of 15° to the south-south-west; but further down the brook it dips at 25°, and terminates in two singular rounded projections, which have evidently been pushed up by the underlying strata. It is succeeded by about one yard of red clays, which bear evidence of considerable pressure having been exerted upon them. Then come regular coal-measures, dipping south-south-west at angles varying from 70 to 80°. These last-named strata are the lower part of the middle coal-field; the whole of the thick beds of this valuable deposit being here covered up by the

upper new red sandstone, and no attempt, that I am aware of, has ever been made to follow them under it.

This section also appears to shew that the trias and permian beds are sometimes unconformable to each other, or some of the latter would have been seen in it.

BEET BANK BRIDGE SECTION.*



This is seen on the banks of the river Tame, about three miles north-east of Stockport. The upper new red sandstone was proved near Reddish Mills, by the late Mr. Becker, in a bore made on his estate to be above 100 yards in thickness, and it runs up the valley to near Arden Hall. Its dip is to the west, at a moderate angle. What beds occur immediately under it cannot be seen owing to the thick covering of drift; but, most probably, permian marls similar to those at Heaton Mersey, exist there, as a red sandstone is found on the rise in the field below Beet Bank Bridge, having the soft crumbling consistency, of the same colour, and exhibiting all the false bedding so characteristic of the lower new red sandstone of Collyhurst. Like the last-named deposit, this bed has also been used for moulding purposes. It lies unconformably on the coal-measures of the middle part of the field, which are seen in the river under the bridge, dipping to the west at an angle of 19° Most probably the trias and permian beds here lie in a trough of coal-measures, and skirt the latter on the south. The late Mr. Fletcher's trustees, in working their little coal, which lies to the north-west of the footpath, leading from Reddish Mills to Beet Bank Bridge, Mr. Peter Higson, mining engineer, informs me, drove their levels south for a

distance of 100 yards under the lower new red sandstone without finding the slightest disarrangement of the coal-measures; thus clearly proving that the latter there run quite regular underneath the permian beds, and are not cut off by them as the coal-miners have often supposed.

Heaton Mersey Section.

At a place lying about four miles to the west of the two last named sections, are the bleach works of Mr. Tait. This is on the dip of the upper new red sandstone, of Stockport, which is about 300 yards in thickness under the town; and some years since, in boring for water there, where that rock was expected to be of very great thickness, it only proved to be 45 feet, and the permian beds, which at Norbury, were of an insignificant thickness, and at Fog Brook, had not been seen at all, were proved to be 540 feet thick. The following is a section of the bore:—

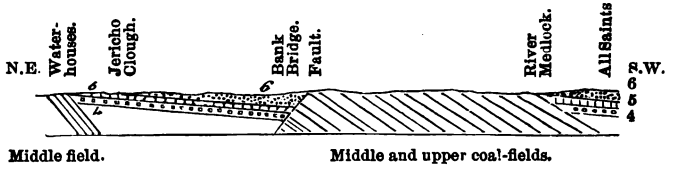
Soil and gravel (a few feet).	Feet.
Upper new red sandstone	45
Red marls containing beds of hard stone.....	129
Lower new red sandstone, proved	402
	576

The last-named deposit, which I examined on the spot as it came up from the bore, consisted of a coarse grained sand of deep red colour, similar to that at Collyhurst. How much thicker this deposit might be it is impossible to say, but it is quite evident that the permian beds extend under the trias of Cheshire, and are of much greater importance there than when seen on their out-crops. Their occurrence at this place, in their present position, is no doubt owing to a great fault, which has thrown them up together with the trias. By carry-

ing the line of the fault which bounds the Manchester coal-field at Bradford and Ardwick, through Heaton Mersey it will run into and connect itself with the fault at the latter place.

The conglomerate bed lying on the top of the lower new red sandstone, although not noticed in the section, occurred here; in fact, the permian beds at this place are a continuation of those at Manchester, under the upper and new red sandstone, and very similar to them both in character and thickness.

MANCHESTER SECTION.



This is taken in a line from All Saints' Church to Water-houses, in the valley of the Medlock. The whole of Chorlton-on-Medlock, and the greater portion of Ardwick, rest upon the upper new red sandstone, which dips to the south-west at an angle of about 10°. At the surface no evidence of the permian beds is to be seen, and even at the outcrop of the upper new red sandstone, a little above Pin Mill Bridge, no traces of these beds are to be met with. This is, no doubt, owing to the permian and overlying trias beds being unconformable to each other, although they both dip in the same direction, and at very similar angles. However, all the borings for water prove the existence of the permian beds, underneath the upper new red sandstone of Manchester.

By the kindness of Mr. William Mellor, of the Ardwick lime works, I am enabled to give the following section, which, although a little to the south-east of the line in the wood-cut, shews well the superposition of the strata under the city.

At Messrs. Thomas Hoyle and Co.'s works, Mayfield, in 1825, a bore hole was made, and the following beds were met with:—

1825.		Ft.	In.
	Upper new red sandstone	143	4
Nov. 8.	Hard rock	1	9
,,	Clay	2	0
9, 11,	All clay	15	9
12.	Clay	0	6
,,	Rock	0	8
,,	Soft rock	0	2
,,	Hard rock	0	2
,,	Clay	0	5
,,	Rock	1	11
14,	Rock	0	7
,,	Clay	0	11
,,	Rock	1	10
15.	Rock	1	3
,,	Soft	0	8
,,	Hard	2	5
16.	Clay	2	4
,,	Rock	0	2
,,	Clay	1	7
17.	Clay	1	3
,,	Rock	3	0
,,	Soft clay	0	3
18.	Rock	1	4
19.	Hard	0	9
,,	Clay	0	6
,,	Hard	1	3
,,	Clay	0	2
,,	Hard	2	4
21, 23.	All hard	7	0
24.	Hard	0	1
,,	Soft	2	10
,,	Hard	0	1
25 to Dec. 1	All hard	7	3
2.	Hard	1	3
,,	Clay	0	3
,,	Soft rock	0	10
,,	Clay	0	4
,,	Soft rock	0	6
3.	Hard rock	2	0
,,	Soft rock	0	8

1845.		Ft.	In.
Dec. 5.	Hard rock	1	6
,,	Clay	0	10
6.	Clay	0	6
,,	Rock	1	10
7.	Hard rock	1	11
,,	Clay	0	8
8, 9.	All clay	5	1
Dec. 10.	Clay	1	11
,,	Clay	0	2
,,	Rock	0	2
12.	Hard rock	0	5
,,	Soft rock	0	5
,,	Clay	1	2
13.	Clay	3	6
,,	Rock	0	5
14.	Rock	0	5
,,	Clay	1	0
,,	Rock	0	9
15.	Rock	0	4
,,	Clay	0	6
,,	Rock	0	2
,,	Clay	0	5
,,	Rock	0	2
16.	Rock	0	2
,,	Clay	2	3
,,	Rock	0	5
17.	Rock	0	3
,,	Clay	1	11
19.	All clay	2	1
20.	Clay	1	0
,,	Light coloured rock	1	2
21.	Rock	0	8
,,	Clay	1	9
22, 24.	All clay	7	4
27, 28, 29, 30, 31; Jan.; to Feb. 4.	All clay	18	1
Feb. 5.	Clay	0	5
,,	Rock	1	9
6.	Rock	0	3
,,	Clay	2	0
7.	Clay	2	0

1846.	Ft.	In.
Feb. 7. Hard raddle	1	0
8, 9. Hard raddle	2	1
10. Hard raddle	1	6
„ Rock	0	5
„ Raddle	2	0
11. Hard raddle	3	3
12. Hard raddle	2	3
„ Rock	0	8
Feb. 13. Rock	0	6
„ Raddle	1	5
„ Rock	1	2
14. Raddle	2	7
„ Rock	0	2
„ Rock	57	4
	355	17

The quantity of work done in the bore each day is given for the purpose of shewing the different degrees of hardness of the strata met with. As is the case with most information of this kind, the men who superintend the borings give their own names to the strata met with, therefore, I think it best to state my opinion as to the nature of the above beds. They may be classed as follow, viz.:—

	ft.	in.
Upper new red sandstone (trias)	143	4
Red and variegated marls, with beds of limestone and impure ironstone (permian)	150	0
Conglomerate (permian)	1	2
Red raddle, with lenticular markings (permian).....	2	7
Lower new red sandstone (permian)	59	4
	356	5

The lower new red sandstone rests unconformably on the highest portion of the upper coal-measures at Ardwick, as I some time since had an opportunity of satisfying myself beyond all doubt, with the assistance of Mr. Mellor, who did me the favour to show me these two formations in contact, during the progress of some of his mining operations. The carboniferous strata, like those described by me in a similar position at Collyhurst, hereinafter noticed, presented every appearance of having undergone considerable erosion by water, the shaly clays shewing a very irregular surface, on which lay rounded boulders of Ardwick limestone, and the hollows in

such clays being filled with lower new red sandstone. There was no trace here of the passage of the carboniferous into the permian strata, and the two are, without doubt, quite unconformable to each other in this locality.

In the turn of the river Medlock, below Mr. Schofield's chapel, the upper new red sandstone has not been seen in absolute contact with the carboniferous strata, but it was traced to within less than one hundred yards of them. They here consist of red and greenish mottled clays, containing a bivalve shell,* and parted by thin bands of gritstone. These last-named strata are succeeded by argillaceous and arenaceous beds of red and variegated colours, containing the limestones and thin coals of Ardwick, which are followed by the coal-measures of Bradford and Clayton, comprising the whole of the known part of the upper and the higher part of the middle division of the Lancashire coal-fields, reaching altogether to about 3,000 feet in vertical thickness, and dipping nearly south-west at angles varying from 18 to 25°. At Bank Bridge, a little to the south of Mr. Wood's print works, the carboniferous strata are thrown down† by a fault of very great, but, as yet, unknown depth, but certainly above 3,000 feet, running from north to south, and covered by upper new red sandstone for a distance of about two miles. All the way from Mr. Wood's to beyond Clayton Bridge, the upper new red sandstone has been proved; and in that gentleman's estate,

* This shell Professor W. C. Williamson, F.R.S., in a paper published in the Phil. Mag., for Nov. 1836, p. 241, called *Unio Phillipsii*, in its compressed state, but to me it appears, when uncompressed, more like a *Modiola* than an *Unio*.

† This fault is generally termed a down throw, but it is very difficult to prove whether it is down or up, for the edges of the carboniferous strata have been so washed and eroded by the action of the waters in which the permian and trias beds were deposited, as to remove all chance of determining the direction of the fault by the usual means.

purchased of the late Mr. Otho Hulme's trustees, the following permian strata were met with in a bore hole:—

	ft.	in.
Drift deposits	96	0
Red metals and rock binds	85	0
Gray rock	4	6
Red metals and rock binds, containing shells of the genera *Schizodus* and *Bakevellia*	28	0
Gray rock	3	6
Red metals, containing rock binds	32	6
Brownish rock	3	0
Red metals, containing rock binds	9	0
Red and variegated rock, penetrated	150	0
	411	6

A little further up the valley of the Medlock, at Jericho Clough, the late Mr. Bradbury, of the Clayton Colliery, found, in a bore hole, the following strata, most of which are permian, viz.:—

	ft.	in.
Drift deposits	64	6
Gray yellowish rock	4	0
Red shaly marl, with bands of white grit	25	6
Soft white rock	1	6
Red floor clay	1	6
Variegated clays	10	6
Whitish limestone	0	6
Red shaly measures, which effervesce in acids	26	0
White gritstone	0	6
Soft red floor clay	1	3
White gypsum * (?)	0	9
Red and white variegated measures	10	6
Hard brown rock, containing lime and iron	2	6
Kind blue shale	0	6
White calcareous rock	0	9
Soft kind blue measures	9	0
Variegated clays	34	6

* This is, no doubt, the white friable paste, met with in the Collyhurst section. Mr. Bradbury himself told me that he very much questioned its being gypsum.

	ft.	in.
Bastard canky stone, very hard	3	0
Soft red floor	1	0
Grit rock, full of sharp grains of quartz that rasped the chisel very much	46	0
Red soft floor	1	0
Dirty brown rock, mixed with tough clayey dirt, very unlikely for coal	34	0
Brown bastard rock	9	0
Red clay floor	6	0
	294	3

Mr. Bradbury did not think the strata favorable for coal, therefore he proceeded no further with the bore. It is doubtful to me whether the lower new red sandstone had been perforated, and the coal-measures reached, especially as the former has been since proved to be of much greater thickness than the whole of the sandstones in the lower part of the section at Jericho Clough.

A short distance below Waterhouses, the coal-measures, most probably part of the middle field, are seen in the bank of the river, dipping westwards at an angle of 60°.

About a mile to the north of the two last-named bores, Mr. Henry Walmsley has bored in his estate at Failsworth, and found the following strata*:—

	ft.	in
Drift deposits	120	0
Red marls	5	4
Red sandstone	333	0
	458	4

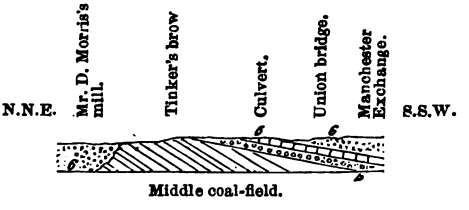
The last-named rock was not perforated, therefore it is difficult to determine whether or not it was the lower new red sandstone or the upper new red sandstone, but the red marls lying on the top of it would rather lead one to suppose that it was the former.

* For this boring I am indebted to the kindness of my friend Mr. Booth, the mining engineer of the Oak Chamber and Chadderton Collieries, Oldham.

From Failsworth to Giant's Seat Lock on the Bury Canal, near Ringley, little if any of the district has been proved by boring, to discover if the permian beds occur or not; but I am inclined to believe, from their regular occurrence all the way from Beet Bank Bridge to Jericho Clough, and probably Failsworth, that they also exist under the drift in a similar position west of Moston Colliery, under Heaton Park and Prestwich, and thence to the valley of the Irwell at Giant's Seat.

The carboniferous strata, seen in the Medlock at Ardwick, were generally supposed to be the highest part of the coal-measures found in Lancashire, but Mr. Mellor has lately shewn me that he has met with beds containing two or three limestones in them considerably higher in position; therefore it is probable that the carboniferous strata may yet be traced further up in the series still, under the permian deposits. Assuming the blackland ironstone, lying above the main limestone at Ardwick, to be identical with the same deposit (Bassy mine) in the Pottery coal-field, near Burslem, there are several hundred feet of red and purple coloured clays, containing thin beds of pebbly gritstone, under the permian beds, and not exposed in the vicinity of Manchester.

COLLYHURST SECTION.



This extends along a line from the Manchester Exchange to Mr. David Morris's mill in the Smedley Valley below Harpurhey.

The south-west part of Manchester and the greater part of the adjoining borough of Salford, are built on upper new red sandstone, like the districts of Chorlton-on-Medlock and Ardwick previously described. To the south of both towns I am not aware of the rock having been perforated, although borings have been made in it to the depth of 600 feet. At Mr. Joules' brewery, near the Albert Bridge, a bore hole was made on the Salford side of the Irwell, and the following strata were met with, viz.:—

	feet.
Upper new red sandstone, about	470
Red clays, with limestones	120
Red rock and clay in alternate beds	10
Hard sandstone rock	000
	600*

The upper new red sandstone may be perforated at a much less depth as you proceed to the northward, as was proved at Messrs. Lomas and Bradbury's, in Strangeways, where the following section was met with, viz.:—

	ft.	in.
Drift deposits	21	0
Upper new red sandstone	273	0
Dark raddle	30	0
Limestone	1	0
Raddle	12	0
Limestone	1	4
Raddle, containing magnesia	30	0
Light gritstone	2	6
Light raddle	24	0
Light stone	1	6
Light raddle	18	0
Dark gritstone	3	6
	407	10

On proceeding to examine the Collyhurst section more in detail, we shall find the upper new red sandstone more or less

* For this section I am indebted to my friend J. P. Joule, Esq., F.R.S.

slightly covered with clay and gravel, occupying the surface from the Exchange to near the White Hart Inn, in Newtown, where it outcrops, and apparently passes into the underlying permian beds, as both dip to the south-west, but the former at an angle of 10°, and the latter at about 13°. It was at this place, many years ago, that I first noticed the fossil shells exposed in making a culvert, and as it is the only locality in the neighbourhood of Manchester, where I have been able to examine the deposits in an open cutting, I shall give my observations at length. The beds occur in the following order:—

	ft.	in.
Red and variegated marls, containing several thin beds of limestone, about	90	0
A layer of soft clay of a dull white colour, mixed with streaks and patches of a dirty red	0	5
*Hard red marl, containing in the middle a single line of shells of the genus *Bakevellia*	9	6
*A white calcareous friable paste resembling fuller's earth, traversed with lines of a red colour	0	5
*A light coloured calcareous paste, of a soft crumbling nature when first dug up, but it hardens on exposure to the atmosphere	0	6
*An argillaceous deposit of a dark red colour, having its top and bottom marked with greenish coloured bands	0	5
*Hard dirty white limestone	0	4
*Variegated marls	0	3
*Dark red marls	1	0
Red and variegated marls	33	0
Impure limestone	0	6
Shaly marls	4	0
Conglomerate of a greenish brown colour, containing pebbles of the size of a marble, seen in Cheetham Weir Hole	1	6
Laminated red clay, with lenticular markings (*Chondrus Binneyi* of King)	2	0
Lower new red sandstone of Vauxhall, consisting of dark red sand, mottled with patches of brown and greenish drab colour, about	320	0
	463	10

The above-named beds, marked with asterisks, contain the fossil shells described by Captain Thomas Brown in my paper published in the first volume of the Transactions of the Manchester Geological Society. Professor King, in his elaborate Monograph on the Permian fossils of England, has since described the following, collected by me from the cutting at Newtown, namely:—BIVALVES, *Schizodus obscurus, S. rotundatus, Bakevellia antiqua, B. tumida and Pleurophorus costatus.* UNIVALVES, *Turbo Mancuniensis, T. helicinus, Rissoa obtusa, R. Leighi, R. Gibsoni,* and *Natica minima.*

Our late venerable president, Dr. Dalton, at p. 154, vol v. (new series) of the Society's Memoirs, examined a portion of the thin bed of limestone. He calls it Tinker's Brow limestone, and states its specific gravity at 2.55, and proceeds as follows: "There is some limestone found at Tinker's Brow which may be supposed an edge of the Ardwick stratum.* The analysis of this specimen shows it to be a compound or mixture of carbonate of lime and clay. The two earths of lime and clay are nearly in atomic proportions; but this may be merely accidental. The lime only is combined with carbonic acid. It contains rather more than the Ardwick stone. Exclusive of iron, I found the compound to be nearly—

Clay	36
Lime	36
Carbonic acid	28
	100"

The lower part of the marls appears to pass into the underlying conglomerate, and no difference in the amount or direction of the dip can be detected. Although such last-named

* The Ardwick limestone and the one at Newtown or Collyhurst were long confounded together as magnesian limestone, but it is now well known that the former is a portion of the upper coal field, and the latter is a true permian deposit.

deposit is but a thin band, it varies so much in its character from all the permian beds either above or below it, in which I have never yet been able to detect portions of rolled mineral matter of the size of a pea, that I think it of considerable importance, and worthy of notice, especially as the conglomerate bed will be found to be of such great thickness as we proceed northwards. The red clays under, unlike the red marls above it, do not effervesce when treated with acids. They apparently pass into the Vauxhall sandstone, so well known as an excellent moulding sand, which I have roughly estimated at 320 feet in thickness; but still, although this conglomerate and its underlying marls seem to graduate into the deposits lying above and below them, I think it more convenient to class them by themselves.

The lower new red sandstone is composed of a dark red sand, variegated by patches of a yellowish drab colour. The upper part of it is much used for the purpose of iron moulding, but the lower portion is not so well adapted for such use, owing to nodules of iron occurring in it. Its grains of sand are well rounded, and are composed chiefly of white quartz, with some pieces of jasper, all coloured red by a slight coating of sesquioxide of iron—so uniform in size are the grains, that anything approaching a pebble has never, to my knowledge, been found in the rock. Its thickness has never been proved by absolute admeasurement, but it must be by my estimate near 320 feet. Its main dip is to the south-west at an angle of from 16 to 18°, but it has also a nearly equal inclination towards the west-north-west.

The upper part of the rock bears evident marks of erosion by the water from which the "till" was deposited. In some places holes two or three feet deep, called by the workmen "posts," are found in the sandstone filled with till, while, at other places, the surface of the rock is only slightly marked or scooped out.

The coal-measures upon which the rock lies consist of a bed

of salmon coloured argillaceous shale of about thirty feet in thickness, containing impressions of *neuropteris cordata*, and many other common coal-plants. Their position in the carboferous series is immediately above the Collyhurst sandstone, and under all the coals which have as yet been worked in the Manchester coal-field, say about 2,250 feet below the uppermost of the carboniferous strata at Ardwick. Their dip is 10° east-of-south, at an angle of 24°. This inclination is not the usual one in the adjoining coal mines of Mr. Buckley, where it is only 18° to the south-south-west, and must be attributed to the fault which has thrown down the coal-measures at the point of junction with the permian beds, and now forms the trough in which the latter lie. In the collieries above alluded to the coals on their strike abut against, or, as the miners express it, are "cut off" by the permian beds.

When the British Association visited Manchester in 1842, an excavation was made to ascertain the state of the lower new red sandstone and the coal-measures at their point of contact. It was then found that the latter strata were mixed with the loose sand of the former, and the coal-measures had lost their original laminated structure and become homogeneous, presenting almost the appearance of drift clay, so that the absolute line of demarcation of one formation from the other could not be determined with any degree of nicety; their colour was a deep red, mottled with marks of a dirty yellow; in fact, their whole appearance, as well as the red and salmon colours of the underlying strata, to a great depth, seemed to shew that they had been long exposed to the action of water before they were covered up by the lower new red sandstone.

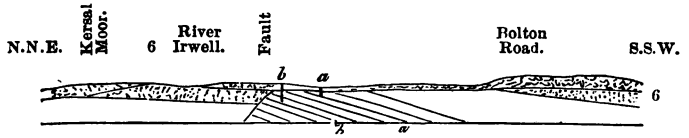
The dip of the two formations does not differ much, that of the coal-measures being at an angle of 24° to a little east of south, that of the lower new red sandstone 17° to the south-west; while the usual dip of the former, the Manchester coal-field, is 18° to south-south-west, the latter from 5° to 10° to the south-west. The coal-measures were doubtless partly

elevated before the deposition of the permian and trias beds, but it is evident that the two latter have been raised by the forces which have subsequently elevated the coal-measures, as the partial similarity of the dip in both strata proves.

The carboniferous strata which next make their appearance are the red sandstones of Collyhurst and Smedley, and afterwards some measures containing a small coal and a bed of fire-clay. These must be approaching near to the thick coals of the middle field, and are cut off by the Bradford and Ardwick fault, near Mr. David Morris's mill. The permian beds lying in this fault have never been proved, although, no doubt, they lie in it in the same manner, and will be found outcropping to the east, as they do at Droylsden and Beet Bank Bridge.

In most of the borings made in the neighbourhood of Manchester, the men employed have frequently classed all the strata gone through, whether arenaceous or argillaceous, as red measures. By these means the red marls will be found to vary very much in thickness, parts of the red sandstones lying above and below them having been frequently added to them. It was owing to this cause that in my first paper printed in the Transactions of the Manchester Geological Society the thickness of the permian marls and their limestones varied so much—the information respecting the strata having been supplied to me by the different well-sinkers and borers whose names are there given as authorities. Taking the sections of Heaton Mersey, Droylsden, Jericho Clough, Mayfield, Salford, Strangeways, and Newtown for our guide, we shall find that the permian marls will generally be from 120 to 130 feet in thickness. As we proceed towards the west we shall find them become thinner, and their accompanying beds of limestone thicker. The limestones in the marls are very uncertain, and seldom found alike even in two bore holes near together. This arises from their occurring in nodular masses rather than continuous beds.

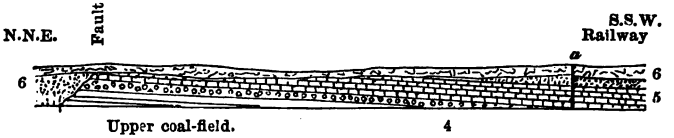
PENDLETON SECTION.



Middle and upper coal-fields.
a and *b* represent Mr. Fitzgerald's old and new pits.

This is met with about two miles north-west of Manchester. It shows the upper new red sandstone at Oatbank, on the Eccles New Road, dipping to the south-west at a moderate angle. Drift covers up the district in the higher parts of Pendleton; but in the valley of the Irwell, Mr. Fitzgerald has worked seams of coal belonging to the upper and middle fields. These dip at an angle of about 18° to the south-south-west, and outcrop against the upper new red sandstone, which there lies in a deep down throw of the coal-measures of full 3,200 feet in extent, of exactly the same character in all respects as the Bradford and Ardwick fault before described. The absolute thickness of the upper new red sandstone lying in this fault is unknown, but it must be near 900 feet. At a depth of 1,350 feet from the surface I have examined red clays found in a level driven into it. They appeared like permian marls, but I could find no fossils in them. They also resemble some red marls seen higher up the valley of the Irwell, at Giant's Seat Lock, near Ringley, which dip under the upper new red sandstone there. Both these deposits of marls I consider as permian, and the red sandstone seen by the side of the great fault in the bed of the Irwell, near Prestolee Foot Bridge, I take to be lower new red sandstone from its characters. In its inferior portion there are also beds of red clay with lenticular markings and thin beds of conglomerate; but I have not yet been able to prove that it dips under the red marls of Giant's Seat Locks. For this reason I have not placed the permian beds in the section shown in the woodcut.

PATRICROFT SECTION.



The Patricroft section is about four miles west of Manchester, near to the Liverpool and Manchester Railway. This is one of the most interesting sections of the trias and permian deposits that I have met with. In the deep coal pit of Messrs. Lancaster, the upper new red sandstone and the permian beds, the clays and limestones of which contained the same fossil shells as I have before stated as having been found at Collyhurst, were sunk through; and in working the coals towards the east, a great fault, filled full of upper new red sandstone, was met with (as shown in the diagram), exactly like those of Manchester, Collyhurst, and Pendleton, previously described.

The shaft marked *a* in the diagram was 440 yards in depth. In sinking it the following strata were met with :—

		Ft.	In.
	Till	15	0
Trias.	White sandstone	2	0
Trias.	Red clays	2	0
Trias.	Red sandstone	15	0
Permian.	Red marls	6	0
Permian.	Red stone	1	6
Permian.	Red marls	4	0
Permian.	White stone	1	0
Permian.	Red marls	9	0
Permian.	Limestone	0	10
Permian.	Red marls	1	6
Permian.	Limestone	1	3
Permian.	Red marls	2	0
Permian.	Limestone	1	0
Permian.	Red marls	1	0
Permian.	Red marls, with several thin beds of limestone	2	6
Permian.	Red marls	1	10
Permian.	Limestone	2	0
Permian.	Red marls	36	0
Permian.	Lower new red sandstone resting on the upper part of the upper coal-field	21	0
		126	5

This bed of lower new red sandstone resembles the conglomerate beds of Norbury and Cheetham Weir Hole rather than the thick deposit at Collyhurst. The trias and permian beds dip nearly due south, at an angle of about 6°. The first-named bed soon crops out,* but the two latter extend some distance, and the coal-measures come in to the north, and form part of the Worsley coal-field. These last comprise 398 yards of the upper field, and dip to the south at an angle of about 8°. They extend upwards from the Pendleton and Worsley four-feet coal to some large nodules of red ferruginous limestone, termed bullions, found just under the red sandstone rock seen in the river Medlock, at Holt Town, Manchester.

Astley Section.

In the No. 28 of the Quarterly Journal of the Geological Society, Mr. G. W. Ormerod gives an account of some borings in the permian deposits, near Astley. In a distance of about ten or twelve feet of permian marls, twenty-eight distinct beds of limestone, parted with beds of red marl, were met with. In this thickness only a portion of the permian marls appears, and nothing whatever is said of the conglomerate and lower new red sandstone.

* The upper new red sandstone in this neighbourhood, especially under Chat Moss, contains a large amount of light carburetted hydrogen-gas. Near Mr. Bell's farm house, on Barton Moss, this gas comes up in such quantity, that he uses it as fuel to heat the boiler of a small steam-engine which he employs for farming purposes. Many years since, Messrs. Lancaster, in boring for coal on the Moss, had previously tapped this gas.

Professor F. C. Calvert made analyses of these marls and limestone, and found the following results:—

	Marl beds.		Limestone.
Insoluble in acids	68.00		16.06
Soluble silica	0.33		1.00
Sesquioxide of iron	7.00		4.66
Alumina	1.33		2.66
Carbonate of lime	18.00		63.04
Carbonate of magnesia	5.00		10.33
Soda	0 34	and potash	0.66
	32.00	loss	0.69
			83.04
	100.00		100.00

By the kindness of Mr. Henry Mere Ormerod, I am enabled to give a section of the strata found in sinking the Engine Pit, at Astley Colliery, on the top of Blackmoor, which is as follows:—

		Ft.	In.
	Upper portion of the shaft bricked so as to hide strata.	27	0
Permian.	Soft white rock	3	10
	Soft red rock	17	5
	Soft gritty white rock	0	9
	Fine red raddle	1	5
	Soft red rock	2	0
	Gray rock	1	1
	Strong red rock	2	7
	White rock	0	10
	Strong red rock	3	1
	Soft red rock	13	6
	Gray stone (bind and lint) *	18	6
	Strong white rock	0	5
	Gray stone (lint)	11	6
	Soft earth (parting)	0	1
	Brown rock	1	1
	White gritty rock	9	0
	Gray metals	0	10
	Bassy coal	0	1
	Soft dirt	0	2
	Clear coal	1	0
		116	2

* This is a local term for strong arenaceous shale.

In this section the red marls and limestones appear to have outcropped on the deep, and only the inferior part of the lower red sandstone was met with. The coal measures, in the lower part of the section, belong to the upper field, and lie above the Worsley four-feet.

By the favour of Mr. H. M. Ormerod, I am enabled to give an account of a boring by George Pixton Kenworthy, Esq., situate in Horse Pasture Field, in the township of Astley, who has liberally allowed it to be published:—

	Ft.	In.
Drift deposits of sand and clay	82	0
Red earth	4	0
White rock	0	6
Red earth, with limestone bullions	2	8
Red earth	5	10
Limestone band	0	2
Red earth	1	4
Limestone band	0	3
Red earth	1	1
Limestone band	0	3
Red earth	3	11
Limestone band	0	4
Red earth	0	2
Red rock full of water	1	5
Red earth	0	8
Limestone band	0	7
Red earth	0	1½
Limestone band	0	7
Red earth	0	3
Limestone band	0	3
Red rock	1	0
Red earth	3	5
Limestone band	0	2
Red earth	5	11
Limestone band	0	3½
Red earth	0	3
Limestone band	0	1½
Red earth	0	1
Limestone band	1	3
Red earth	0	1¼
Limestone band	0	8½
Red earth	3	7
Limestone band	0	8
Red earth	0	9
Red rock	1	7
Red earth	0	5
Red rock full of water	1	8
Red earth	0	5
Red rock	5	2
Red earth	1	3
Limestone band	0	6
Red earth	6	9
Limestone band	0	2½
Red earth	0	1⅛
Limestone rock full of water.	3	3½
Red earth	7	8
Limestone band	0	1
Red earth	0	11
Limestone band	0	5
Red earth	0	2
Limestone band	0	5
Red earth	2	3
Limestone band	0	1½
Red earth	0	1
Limestone band	1	1½
Red earth	0	2½
Limestone band	0	5
Red earth	0	6
Limestone band	0	1
Red earth	0	6
Limestone band	0	0½
Red earth	0	0½
Limestone band	0	1
Red earth	0	10
Limestone band	0	2
Red earth	0	1

	Ft.	In.
Limestone band	0	1
Red earth	0	1
Limestone band	0	2
Red earth	0	1½
Limestone band	0	2
Red earth	0	0½
Limestone band	0	1
Red earth	0	1¼
Limestone band	0	1¾
Red earth	0	2
Limestone band	0	3¼
Red earth	0	3
Limestone band	0	3
Red earth	0	4½
Limestone band	0	2½
Red earth	0	4
Limestone band	0	2
Red earth	0	0½
Limestone band	0	1½
Red earth	0	1
Limestone band	0	1½
Red earth	0	9
Limestone band	0	1⅝
Red earth	1	0
Limestone band	0	1
Red earth	0	0½
Limestone band	0	2
Red earth	0	3

	Ft.	In.
Limestone band	0	2
Red earth	0	4
Limestone band	0	3¼
Red earth	7	9½
Iron band	0	1½
Red earth	13	6
Limestone band	0	1
Red earth	1	0
Limestone band	0	2
Red earth	0	1
Limestone band	0	1
Red earth	3	1
Limestone band	0	1
Red earth	1	0
Limestone band, very hard	0	5
Red earth	0	1
Limestone rock, very hard	0	8¼
Red earth	0	8½
Hard burry limestone rock	2	7
Red earth	5	1
Red linsey	3	7½
Red sandy earth	1	7
Limestone rock	0	6½
Red earth	0	4½
Limestone rock gone into	1	0
	212	10

The permian marls in the above section must have been nearly perforated, but the conglomerate appears not to have been reached. The number of thin beds of limestone in the "red earth" (a local term for red marls) is the greatest that has yet been met with in the north-west of England. It is to be hoped that Mr. Kenworthy will preserve as careful a section of the conglomerate and lower new red sandstone beds as he has done of the marls.

Bedford Section.

After the outcrop of the upper new red sandstone, which is seen dipping to the south, in a field near the Manchester

and Wigan Canal, where the late Mr. Coleby formerly had his lime works, beds of limestone parted with red clays, similar to those at Astley, have been worked here for many years. The limestones are full of fossil shells of the same genera as those met with at Collyhurst, and before described in this paper, as well as numerous sponges, one of which Professor King has figured and described in his work on the Permian Fossils as *Tragos Binneyi*.

A complete section of the permian beds in this locality is wanted. The late Mr. Coleby informed the writer that the thickness of the marls was about 60 feet; ten feet of this consisting of limestone in numerous beds. He also considered that there was a bed of sandstone above, as well as one under the red marls.

Mr. Whitehead, solicitor, of Leigh, the proprietor of the Bedford Lime Works, has favoured me with the following section of the strata met with in his sinking:—

	Ft.	In.
A bed of limestone, called false band	0	5
Red clay	3	0
Band stone (this is the best stone).....	1	0
Red clay...	1	0
Limestone	0	7
Red clay with thin beds of limestone the beds each about one inch thick, clay and stone alternating, the former rather thicker than the latter	3	0
Strong red clay.....	1	0
Red clay with beds of limestone, the latter of which will vary from one to seven inches in thickness ...	3	0
Red clay	1	0
Limestone.....	0	1½
Red clay with beds of limestone, the top course of stone 12 inches in thickness, called second band; some of the beds of clay are 12 inches in thickness. The layers of stone vary from one to three inches in thickness. The stronger the stone, the thinner the clay	10	0
	24	1½

In an open work belonging to the trustees of the late Duke of Bridgewater, I lately inspected the limestone, and found it there lying nearly level. The first bed was about seven inches in thickness, then came red clay six inches, after that limestone five inches, next several beds of about an inch each, parted by clays. The limestone (5) was hollowed out in this way:—

and filled up with bluish-coloured till, which was there from twelve to fourteen feet in thickness.

Mr. Hugh Watson, chemist, of Bolton, analysed a sample of the Bedford limestone, and found the following results:—

Carbonate of lime	46.5
Aluminous and siliceous earths	48.5
Oxides of manganese and iron	2.5
Water	2.5
	100

The beds of sandstone under the marls and limestones have not been much examined, but they certainly occur lying above the coal-measures at Bedford Colliery, where the Worsley four-feet is worked. I have not been able to examine these beds *in situ*, but after sinking through the permian marls and limestones at the adjoining colliery, the property of Messrs. Samuel Jackson and Co., a bed of red and variegated sandstone was met with, 135 feet in thickness, on the top of which was a singular-looking sandstone of a greenish brown colour, mottled with red marks, containing a good deal of per oxide of iron and nodules of red clay. This, from examination of the specimens of rock now lying on the pit bank, I have little doubt but of its being the conglomerate bed lying immediately under the marls. In some of the sandstones there appear impressions of *calamites*, *sigillaria* and fossil wood, but whether they belong to the permian or carboniferous strata,

as both are lying on the pit bank mixed together, I will not undertake to speak positively. If they belong to the former, they are the only fossil plants that have as yet, to my knowledge, been found in the permian beds of the north-west of England. These beds dip a little east-of-south, at an angle of about 8°, and the underlying coals dip nearly south, at an angle of 14°.

ATHERTON SECTION.

N.N.E. S.S.W.

This section is near Leigh, and is exposed in the small brook course which enters the land, formerly part of Atherton Park, from the north. On the banks of this stream, up to a little past the small bridge, the upper new red sandstone appears dipping at an angle of about 8° to 10° to the south. It is then seen gradually passing first into beds of red marl, containing thin bands of hard gritstone, and afterwards into deposits of red laminated marls containing numerous beds of limestone. The largest of these is about 1ft. 8in. in thickness, and there are several beds of from two to four inches, besides others of less dimensions. All these are full of fossils of the genera *Schizodus*, *Bakevellia*, *Turbo*, and *Tragos*, but apparently contain little or no magnesia in their composition.

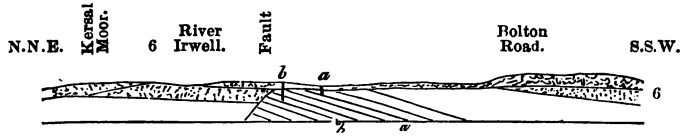
The dip of the strata is to the south, at an angle nearly similar to that of the upper new red sandstone above alluded to. In proceeding up the brook-course towards the mill, however, their dip becomes greater, reaching to an angle of 16°, and is to the south-west instead of the south. They are succeeded by nodules of irony limestone of a purpleish colour, containing sparry matter, and then by the lower new red sandstone, about seven yards in thickness. This latter rock dips

elevated before the deposition of the permian and trias beds, but it is evident that the two latter have been raised by the forces which have subsequently elevated the coal-measures, as the partial similarity of the dip in both strata proves.

The carboniferous strata which next make their appearance are the red sandstones of Collyhurst and Smedley, and afterwards some measures containing a small coal and a bed of fire-clay. These must be approaching near to the thick coals of the middle field, and are cut off by the Bradford and Ardwick fault, near Mr. David Morris's mill. The permian beds lying in this fault have never been proved, although, no doubt, they lie in it in the same manner, and will be found outcropping to the east, as they do at Droylsden and Beet Bank Bridge.

In most of the borings made in the neighbourhood of Manchester, the men employed have frequently classed all the strata gone through, whether arenaceous or argillaceous, as red measures. By these means the red marls will be found to vary very much in thickness, parts of the red sandstones lying above and below them having been frequently added to them. It was owing to this cause that in my first paper printed in the Transactions of the Manchester Geological Society the thickness of the permian marls and their limestones varied so much—the information respecting the strata having been supplied to me by the different well-sinkers and borers whose names are there given as authorities. Taking the sections of Heaton Mersey, Droylsden, Jericho Clough, Mayfield, Salford, Strangeways, and Newtown for our guide, we shall find that the permian marls will generally be from 120 to 130 feet in thickness. As we proceed towards the west we shall find them become thinner, and their accompanying beds of limestone thicker. The limestones in the marls are very uncertain, and seldom found alike even in two bore holes near together. This arises from their occurring in nodular masses rather than continuous beds.

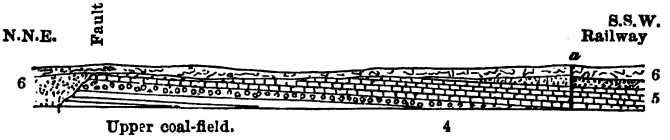
PENDLETON SECTION.



Middle and upper coal-fields.
a and *b* represent Mr. Fitzgerald's old and new pits.

This is met with about two miles north-west of Manchester. It shows the upper new red sandstone at Oatbank, on the Eccles New Road, dipping to the south-west at a moderate angle. Drift covers up the district in the higher parts of Pendleton; but in the valley of the Irwell, Mr. Fitzgerald has worked seams of coal belonging to the upper and middle fields. These dip at an angle of about 18° to the south-south-west, and outcrop against the upper new red sandstone, which there lies in a deep down throw of the coal-measures of full 3,200 feet in extent, of exactly the same character in all respects as the Bradford and Ardwick fault before described. The absolute thickness of the upper new red sandstone lying in this fault is unknown, but it must be near 900 feet. At a depth of 1,350 feet from the surface I have examined red clays found in a level driven into it. They appeared like permian marls, but I could find no fossils in them. They also resemble some red marls seen higher up the valley of the Irwell, at Giant's Seat Lock, near Ringley, which dip under the upper new red sandstone there. Both these deposits of marls I consider as permian, and the red sandstone seen by the side of the great fault in the bed of the Irwell, near Prestolee Foot Bridge, I take to be lower new red sandstone from its characters. In its inferior portion there are also beds of red clay with lenticular markings and thin beds of conglomerate; but I have not yet been able to prove that it dips under the red marls of Giant's Seat Locks. For this reason I have not placed the permian beds in the section shown in the woodcut.

PATRICROFT SECTION.



The Patricroft section is about four miles west of Manchester, near to the Liverpool and Manchester Railway. This is one of the most interesting sections of the trias and permian deposits that I have met with. In the deep coal pit of Messrs. Lancaster, the upper new red sandstone and the permian beds, the clays and limestones of which contained the same fossil shells as I have before stated as having been found at Collyhurst, were sunk through; and in working the coals towards the east, a great fault, filled full of upper new red sandstone, was met with (as shown in the diagram), exactly like those of Manchester, Collyhurst, and Pendleton, previously described.

The shaft marked *a* in the diagram was 440 yards in depth. In sinking it the following strata were met with :—

		Ft.	In.
	Till	15	0
Trias.	White sandstone	2	0
	Red clays	2	0
	Red sandstone	15	0
Permian.	Red marls	6	0
	Red stone	1	6
	Red marls	4	0
	White stone	1	0
	Red marls	9	0
	Limestone	0	10
	Red marls	1	6
	Limestone	1	3
	Red marls	2	0
	Limestone	1	0
	Red marls	1	0
	Red marls, with several thin beds of limestone	2	6
	Red marls	1	10
	Limestone	2	0
	Red marls	36	0
	Lower new red sandstone resting on the upper part of the upper coal-field	21	0
		126	5

This bed of lower new red sandstone resembles the conglomerate beds of Norbury and Cheetham Weir Hole rather than the thick deposit at Collyhurst. The trias and permian beds dip nearly due south, at an angle of about 6°. The first-named bed soon crops out,* but the two latter extend some distance, and the coal-measures come in to the north, and form part of the Worsley coal-field. These last comprise 398 yards of the upper field, and dip to the south at an angle of about 8°. They extend upwards from the Pendleton and Worsley four-feet coal to some large nodules of red ferrugineous limestone, termed bullions, found just under the red sandstone rock seen in the river Medlock, at Holt Town, Manchester.

Astley Section.

In the No. 28 of the Quarterly Journal of the Geological Society, Mr. G. W. Ormerod gives an account of some borings in the permian deposits, near Astley. In a distance of about ten or twelve feet of permian marls, twenty-eight distinct beds of limestone, parted with beds of red marl, were met with. In this thickness only a portion of the permian marls appears, and nothing whatever is said of the conglomerate and lower new red sandstone.

* The upper new red sandstone in this neighbourhood, especially under Chat Moss, contains a large amount of light carburetted hydrogen-gas. Near Mr. Bell's farm house, on Barton Moss, this gas comes up in such quantity, that he uses it as fuel to heat the boiler of a small steam-engine which he employs for farming purposes. Many years since, Messrs. Lancaster, in boring for coal on the Moss, had previously tapped this gas.

		Ft.	In.
	Red stone	11	6
	Red metal	25	6
	Red burr (hard rock)	2	8
	Red metal	26	3
	Brown metal	1	0
	Red rock	82	0
Carboniferous.	Metal	41	0
	White rock	17	0
	Burr	4	3
	Metal	0	9
	White rock	12	0
	Blue metal	27	3
	Little Delph coal	3	9
	Warrant	1	0
	Black bass	4	0
	White metal	2	0
	Gray rock	18	3
	Burr	4	6
	Rock	12	6
	Metal	17	0
	Main Delph coal	7	0
		482	1

The trias and permian beds in this section have the same angle of dip, namely 7° east-of-south, at an angle of 14°, whilst the underlying coal-measures dip 52° east-of-south at angle of 11°; so it is evident that the former have a greater inclination than the latter. These appear to have been partly eroded and removed before the deposition of the trias and permian beds, and afterwards all three formations have been elevated into their present position.

Mr. Evans's two pits are about 50 yards apart, and the trias and permian strata were met with in the bye pit, 50 yards higher up than in the engine pit. The red stone of 10ft. 6in. no doubt represents the thin beds of limestone parted by clays, and the red burr of 2ft. 8in. the lower band of the Bedford section. The same fossils were found in the limestone as at Bedford. The lower new red sandstone, although described as red, had beds of a light colour mixed

with it. The miners who were engaged in sinking the pits informed me that the last named rock contained much water, and was composed of very sharp grained sand, which rasped their tools quickly

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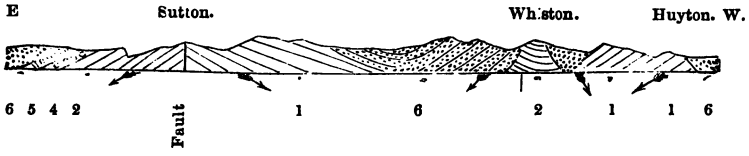


SUTTON SECTION.

The upper new red sandstone is seen by the side of the lane leading to the station on the Liverpool and Manchester Railway. It consists of reddish sand without much cohesion. The dip is rather difficult to make out, but it seems to be towards the east. Under this sandstone dip 30 feet of red and greenish mottled marls, containing small lenticular markings, and dipping at an angle of 10° to the east-south-east. In these beds Mr. Smith, a gentleman residing in the neighbourhood, and well acquainted with the strata, informed me that he had found nodules of limestone and impressions of shells. Then comes a rock of about 90 feet thick of red and variegated sand used for moulding purposes, and dipping under and in the same direction as the marls last mentioned. Although this sandstone has only been proved 90 feet, Mr. Smith estimates its thickness at above 300 feet. On the top of it are found large nodules, some of them half a ton in weight, very hard, and when broken showing a mottled appearance, and containing a good deal of red marl and peroxide of iron. They at first sight might be taken for conglomerates, but to me they are more like chemical aggregations of different substances from a pasty state than rolled pebbles. Whatever their origin, they cannot be distinguished from the

bed previously described at the Bedford Colliery, and would appear to prove that the conglomerate at the latter place occurred on the top of the lower new red sandstone. They, therefore, are most probably the representatives of the Norbury and Cheetham Weir Hole beds. The marls and sandstone, both which I consider as permian, rest on upper coal-measures of a red colour, seen in the dam of the London and Manchester Plate Glass Company. When this dam was making I found fossil shells of the genus Modiola, so often met with in the upper coal-measures. Next come on the red clays, parted by thin bands of variegated grits seen in the Sutton Railway cutting. These red coloured strata I could not measure, but Mr. Smith informed me that Mrs. Hughes had bored in her field north of the Liverpool and Manchester Railway to the depth of 80 yards without meeting with any seam of coal of a workable thickness. They dip to the east-south-east, at an angle of 17°. At the workhouse Bridge across the line is seen a fault that brings up coal-measures of the middle coal-field, which appear dipping south-south-west at an angle of 16°. Thus an anticlinal axis is formed, with trias, permian and coal measures of the upper field, the latter resembling the North Staffordshire beds, and like them having been long worked as clays for the manufacture of coarse pottery, on the east side, and middle coal-measures on the western side. In the fault the clays and grits are much altered, as if by the effects of pressure and heat. On proceeding towards the west the coal-measures dip less and less, until they become nearly level, when they disappear under the drift. The upper new red sandstone is not seen on the railway, but at Thatto Heath, to the north of the line, it occurs as a strong conglomerate, dipping westwards, and continues as far as the station at Kenrick's Cross.

Whiston Section.

Proceeding towards Liverpool, after leaving the Railway Station at Kenrick's Cross, the upper new red sandstone is seen taking a moderate dip to the west. Near the Wooden Bridge, at Whiston, it appears a good deal fractured, and dips south-south-east,* at an angle of 25°, is much discoloured, and traversed by joints containing black oxide of manganese. The dip increases to an angle of 65° east of the bridge, and then 98 yards of coal-measures are seen protruding through the sandstone. These strata belong to the upper coal-field, and consist of red and greenish mottled clays, containing a bed of limestone, about two feet in thickness, resembling that found at Ardwick, and a rock of reddish gritstone on the east of the bridge. The strata dip to the west at an angle of 24°, which gradually diminishes as you proceed westwards until they reach the upper new red sandstone, where it is only 5°. Three or four inches of soft red clay intervene betwixt the coal-measures and the upper new red sandstone. The last-named rock, when it appears, is much discoloured. At first its angle of dip is 50° to the west, but this soon lessens to 30°, and it then, in the distance of a few hundred yards, disappears, and is succeeded by the Halsnead and Huyton coal-field.

Huyton Section.

After the disappearance of the upper new red sandstone in the last section, some of the higher portions of the Halsnead coal-field are seen on the railway dipping eastwards, but no good section appears until you reach the Huyton Flag Quarry. The flag-rock there seen is the one well known in the neighbourhood of Bury and Rochdale as the Upper Flag or Old

* This dip appears to have been originally to the west, but by the protrusion of the coal-measures is altered to the south-south-east.

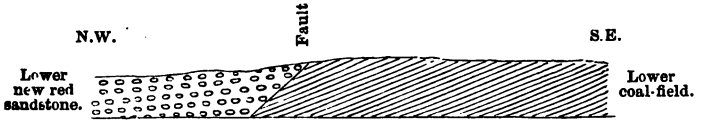
Laurence Rock. In the west of Lancashire it is called the Upholland Flag, and is always known to overlie the lower coals. It dips to the south-east, at an angle of 26°, and some of its lowest beds on their rise abut against the upper new red sandstone lying in the valley below, and extending from there to beyond Liverpool without interruption. The occurrence of the upper new red sandstone on the rise of the coal-measures seems to indicate a great downthrow of the latter filled up with red sandstone. Where the coals come up again to the west remains yet to be proved. The upper new red sandstone, when next seen on the railway near Broad Green, dips eastwards.

The last three sections afford us valuable information as to the different characters of the dislocations which have broken up the coal-field. The first of them exhibits an anticlinal axis, showing that the carboniferous, permian and trias beds have been affected by the Sutton fault; the Whiston section shows the protrusion of the carboniferous strata through the trias without exposing any of the permian beds; but the coal-measures of Halsnead and Huyton were most probably elevated before the new red sandstone was deposited on their western flanks. This last-named rock, no doubt, overlies a great mass of coal-measures between Huyton and Liverpool. Betwixt Liverpool and the Irish Sea, few, if any, searches for coal have been made to my knowledge; but if the upper new red sandstone can be found cropping out to the west, there is every reason to believe that coals will be met with under it. On the other hand, if this sandstone west of Liverpool dips westward, the coals will be at a great depth.

In all the attempts which have been made at Liverpool in sinking and boring for water I am not aware of the upper new red sandstone having been perforated, although some of these bores reached about 600 feet in depth. If the last-named rock could be gone through, there is no reason to

doubt that the permian beds would be found under it, as is the case at Manchester and other places. The lowest portion of this last group, that is to say, the lower new red sandstone, holds immense volumes of water, and it is rather surprising that no attempts have been made to reach it by boring. In all the expensive and laborious investigations by geologists and engineers in the contest for the New Water Works at Liverpool little attention was paid to this fact. If a tithe of the money spent in the legal fight had been judiciously expended in making a deep bore-hole, it is most probable that the town would have been supplied with plenty of water, and much valuable information on the geology of the district would have been afforded to the public; at any rate, an entirely independent supply of water would have been obtained in addition to that now derived from the upper new red sandstone.

GRIMSHAW DELPH SECTION.



This quarry is situated in the western part of Upholland, and is composed of rough rock, one of the lowest members of the coal formation above the millstone grits. Its dip is to the north-north-west, at an angle of 16°. On its dip it is traversed by a great fault, running from south-east to north-west, which brings in a rock which I consider to be lower new red sandstone. This deposit has a slight dip to the north-west, and has been used as a moulding sand. It is from its consistency, grain, colour, and general appearance, that I class it as a permian deposit, for I can get no evidence of the strata which lie above or under it, owing to the covering of drift which envelopes the district. Its thickness I cannot ascertain, but

probably fifteen feet of it may be exposed. The fault in which it lies is a continuation of that seen below Billinge Beacon, which brings in the Rainford coal-field.

Scarisbrick Section.

By the kindness of my friend, Mr. John Hawkshead Talbot, I have been favoured with the result of borings, made by Charles Scarisbrick, Esq., near Scarisbrick Hall, some years since. It is as follows :—

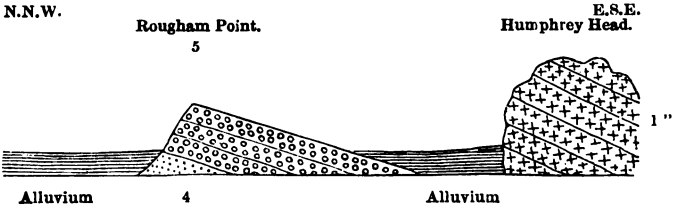
	Ft.	In.
Soil	3	0
Brown sand	4	6
Brown clay	1	7
Variegated marl	230	8½
White grit pebble	0	7½
Variegated marl	18	0
Blue loam	4	2
Flaggy marl	3	0
Blue grit list*	19	3½
Brown strong rock list	1	1
Limestone list and limestone shale	7	4⅓
Brown flint kernel	1	7
Blue cast grit	2	0
Brown open grit	1	10
Blue shale	6	8½
Brown flint pebble	0	4
Blue shale	0	5
	306	2⅓

This boring appears to me to be on the rise of the upper new red sandstone of the neighbourhood, and if so, it most probably represent the beds lying under that rock, namely, the permian deposits. They for the most part resemble the upper portion, the marls, limestones, and conglomerates, and shew that the thickness of this part of the permian group increases much towards the west.

* This term is used to denote a series of bluish grits, parted with softer beds.

Across the low country northwards, extending to the Ribble and thence along the Fylde district and other parts of North Lancashire, I am not aware that any evidence has yet been obtained of the existence of permian beds until we reach Rougham Point, near Humphrey Head, Flookborough, and the small village of Stank both across Morecambe Bay, in the hundred of Furness. The former of these I shall now shortly describe.

ROUGHAM POINT SECTION.



Professor Sedgwick states "that the red sandstone is probably expanded under the low region at the south-western extremity of Cartmel Fells, as it is said to have been reached in two places by excavations, and it appears as a very characteristic conglomerate, unconformable to the mountain limestone near Flookborough Spaw. No traces of it have, I believe, been discovered on the neighbouring coasts of Westmoreland and Lancashire; but it re-appears (far beyond the limits of the country I am attempting to describe) in a small patch, at West House, near Ingleton; as has been already noticed by Professor Phillips."* Also, "that in the Cartmel promontory the new red conglomerates appear at Rougham Point, west of Humphrey Head; and the red sand-

* On the New Red Sandstone Series in the basin of Eden and North-West coasts of Cumberland. Transactions of the Geological Society, vol. IV. (2nd series) p. 389.

The same Memoir, p. 407.

stone is said to have been reached by boring between Cannon Winder and Ravend's Winder, and close to Lower Hosker."

After having only seen the small conglomerate bed of South Lancashire of but two or three feet in thickness, and at Sutton only occurring in nodules, I was surprised to meet at Rougham Point, near Humphrey Head, south of Flookborough, with a bed of red conglomerate of full 50 feet in thickness. It is exposed to this extent, and bears evidence of a considerable portion having been removed by the action of the waves of the sea. The pebbles composing it are of all sizes up to that of a man's head; many of them being rounded and others angular. They chiefly consist of the mountain limestone of the district, some of the latter being hollow and filled with spar. There are also a few dark-coloured red sandstones and pieces of red ironstone, all cemented together by a weak sandy calcareous cement. The stone is known in the neighbourhood by the name of "cement stone." It is regularly stratified, and parted in some places by beds of soft sand of a dark red colour, and at its base appears to pass into a slightly coherent red sandstone of great thickness. This last rock appears to have reached from 400 to 500 feet in depth, judging from the space left between it and the mountain limestone; but it is now washed away, the sea having apparently removed it all the distance to the west and north, and left the conglomerate as an island surrounded by marsh land (alluvium), having the mountain limestone of Humphrey Head to the east and that of Lower Allithwaite to the north, to both of which it is evidently unconformable.

The limestone of Humphrey Head dips to the east-north-east at an angle of 15°, and the conglomerate and lower new red sandstone dip to the east-south-east at an angle of 10°.

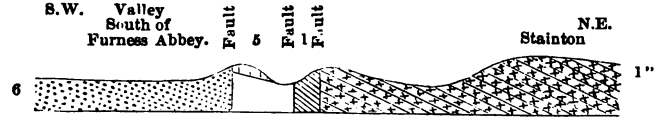
The pieces of limestone in the conglomerate, especially the large ones, are regularly stratified, and bear every evidence of having been arranged by water; and the sea at high tides removes the stones out of their cement, and after rolling

them about deposits them as shingle, very much in the same manner as they are seen in the stone. The beds of soft red sandstone parting the rock very much assist in disintegrating the mass, and allowing the waves to sap the base.

In the islands of Morecambe Bay and the main land of Furness, probably some traces of the conglomerate and lower new red sandstone may be met with, occupying hollows in the mountain limestone, but the vast covering of drift hides the country so much that it is very hard to get a sight of strata like the permian.

In passing over Morecambe Bay from Barrow, Bardsea and Piel, I have been informed by the captains of packets that there were several ledges of sunken rocks of a red colour seen in the bay at very low tides. In all probality these are permian strata.

STANK SECTION.



This is exposed in a field at Holbeck, about a mile and a-half to the south-east of Furness Abbey, on the road side leading from Stank to Newton. In it occurs a bed of yellowish brown magnesian limestone, more resembling the great Yorkshire deposit than any hitherto described in this paper. Unfortunately, only a thickness of two yards is exposed in a small quarry of a few yards in extent. The dip of the stone at the north-east end of the quarry was 18 to 20° to the south-east; but at the south-west end it was to the south-west at an angle of 13°. The former appears to me to be the true dip. The section in the woodcut is in a great measure ideal, for neither the strata under, nor those above

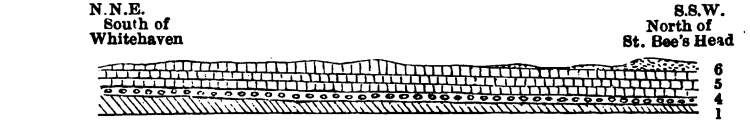
the limestone can be seen in contact with it. The deposit is succeeded on the rise by the upper new red sandstone, dipping, when next seen, to the south-east, and on the deep some coal shales make their appearance for a short distance. Then comes the mountain limestone of Urswick. Nothing has been seen by me of the conglomerate and lower new red sandstone. No fossils have, to my knowledge, been met with in the limestone; but cavities occur in it having the shape of casts of *Bakevellia* and *Schizodus*.

By the kindness of my friend Mr. James Gibb, chemist, I am enabled to give the following analysis of a part of the upper portion of the Holebeck stone. It is as follows:—

Carbonic acid	38.40
Silica	11.65
Magnesia	8.95
Oxide of iron	9.45
Lime	29.80
Water	1.75
	100.00

The coal-measures seen on the deep of the limestone appear to belong to the middle coal-field. They contain shells like the *Unio acutus*, fish scales, and remarkably large *curls*, or *coralloid cones* as they are sometimes termed, in a bed of poor clay ironstone.

Barrow Mouth Section.



From Stank across the Duddon, round by Black Coomb, and thence by Ravenglass and Drigg to St. Bees, the upper new red sandstone appears to underlie the country. Between St. Bees' Head and Whitehaven, at Barrow Mouth, a most

beautiful section of the permian beds is seen. After the fine development of the upper new red sandstone of St. Bees' Head, of from 600 to 700 feet in thickness, by means of a dislocation in the shape of an upthrow, the permian beds are brought in, and consist of the following deposits finely exposed in the cliff, namely:—

		Ft.	In.
	Upper new red sandstone	0	0
Permian.	Red marls, about	30	0
	Red marls, containing most beautiful white granular gypsum, about	29	1
	Magnesian limestone, of a cream colour, containing casts of *Bakevellia*, *Schizodus*, and other shells	10	6
	Coarse sandy conglomerate, containing pebbles of the size of a man's head	3	0
	Red and purple coloured sandstones of great thickness, generally described as lower new red sandstone.		
		72	7

The conglomerate, many of the pebbles of which are hollow and contain crystals of carbonate of lime, rests on purple-coloured sandstones with a very uneven surface, the latter having been a good deal eroded and subsequently filled up with sandstone. The dip of all the beds appears to be about the same, viz., 10° to the south-south-west. The red marls, (the lower of which contains a very thick bed of the finest white granular gypsum I ever saw, full 25 feet in thickness,) the limestone, and the conglomerate, are without doubt all members of the permian group. The purple sandstone is generally considered by Professor Sedgewick and others to be lower new red sandstone overlying the coal-measures of Whitehaven; but with all respect to so great an authority, I am inclined to believe that it is a carboniferous sandstone.

The two compact beds of yellow magnesian limestone at Stank and Barrow Mouth, above described, are very unlike in their appearance to the ribbon beds and nodules of impure limestone found in the red marls of South Lancashire; but they have great resemblance both in colour, structure, and

composition, to the magnesian limestone found at Cultra on the south side of Belfast Lough.* According to Sir Robert Kane, the limestone there is sixty feet in thickness, and 100 parts of it on analysis gave—

Magnesia	22.1
Lime	30.3
Carbonic acid	47.6
	100 0

In some notes which I took of the Cultra beds when I attended the meeting of the British Association at Belfast in 1852, I find that on proceeding from west to east, these strata consisted of dark-coloured shales, impure limestones, and red sandstones, some of the latter being of a conglomerate character. The two first-named deposits contained a bivalve shell resembling a *Modiola*, remains of entomostraca, one of which is like a *Cypris*, scales of fishes of the genera *Holoptychius* and *Palæoniscus*, and fragments of common coal-measure plants. All the fossils reminded me of those found in the upper carboniferous strata at Ardwick, near Manchester; but the sandstones were much coarser in structure and bore more resemblance to the higher coal-measures seen near Stoke-upon-Trent and the Potteries. The strata are very much cut up by trap dykes, so it is very difficult to draw a true section shewing the actual superposition of the beds. However, past Cultra landing-place there is beyond all doubt as good a magnesian limestone as any in Yorkshire, containing shells of the genera *Schizodus* and *Bakevellia*. Red sandstones occur both above and below this limestone; but the undermost one is quite a conglomerate, and I took it without hesitation to be permian.

The limestone is of a warm yellow colour, and was formerly shipped to Liverpool for the purpose of being used in the manufacture of magnesia.

* The Industrial Resources of Ireland. By Sir Robert Kane, F.R.S., &c., p. 246.

I am aware that the veteran geologist of Ireland, Dr. Griffith, F.R.S., and Professor Mc. Coy are inclined to consider this limestone yellow sandstone, but Mr. Mc. Adam, a good local geologist, who has often investigated the section, has no doubt as to the bed being true magnesian limestone; Professor William King, whose knowledge on such a point is of the highest value, is also of the same opinion; so I think Ireland will still retain in its geology this small portion of magnesian limestone, none other having ever to my knowledge yet been met with in the whole country.

Kirkby Stephen and Brough Sections.

In the upper part of the valley of the Eden, lying between Kirkby Stephen and Brough, is a very interesting deposit of calcareous conglomerate, somewhat similar in appearance but of far greater thickness and importance than the one previously described at Barrow Mouth. This valley from the sea to the south of Appleby more or less shews the presence of the upper new red sandstone, but, so far as my knowledge extends, no trace of the permian beds has been met with in the district until we reach the neighbourhood of Brough. From this last-named place to Stenkreth Bridge, beyond Kirkby Stephen, they occupy a considerable extent of country, evidently lying in a trough of carboniferous limestone, and displaying themselves in the brook and river courses, overlying the carboniferous limestone; but not affording any section which I am aware of that shews their relation to the overlying upper new red sandstone.

I use the term conglomerate in this district, as well as at Bedford and Sutton,* to characterise the deposit, as being

* Specimens of the Bedford and Sutton stones in my cabinet scarcely can be distinguished from those found at the base of the magnesian limestone, at Kirkby Woodhouse, Nottinghamshire, and described by Professor Sedgwick in his paper on the magnesian limestone of the north of England.

well known and in common use, without committing myself to any views as to its origin. Some portions of this deposit to my mind shew as much resemblance to a segregation of particles when in a pasty state by chemical affinity, as a collection of rolled fragments of ancient rocks cemented together with carbonate of lime; although I do not deny that many angular and rolled pebbles are certainly found in it. In some instances the pebbles form the chief part of the rock, and in others the cement. Few fossil remains appeared to me in the specimens of limestone which I examined in the neighbourhood of Kirkby Stephen and Brough, and many of them, although, on the outside looking like boulders, are hollow, resembling potato stones, and filled with crystals of carbonate of lime.

Near Stenkreth Bridge, the conglomerate, there known by the local name of "bruckram," consists of two beds, the uppermost one of a hard and compact kind, quarried and used for building purposes, and the lower one of a much softer description, known by the name of "rotten bruckram." At first I was inclined to think that there was but one bed, and that the lower portion of it had been acted upon by water so as to soften it; but from information which I gathered on the spot I am disposed to think that there are two distinct beds.

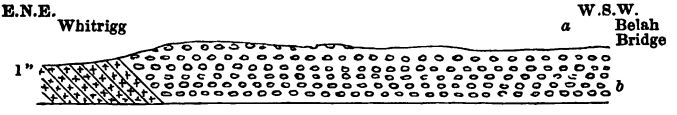
Their thickness, so far as I could estimate it, would be as follows, viz.:—

	Ft.	In.
Hard bruckram, used for building	16	0
Soft rotten bruckram	12	0
	28	0

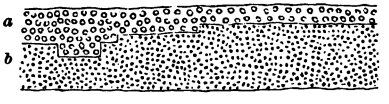
Both these beds lie nearly level, the dip of the first in Stenkreth quarry, near the bridge, being from 7 to 8° to the south-east. They continue to be seen in the river Eden all the way from Stenkreth Bridge to the bridge on the north of

Kirkby Stephen, on the Brough road, without much alteration, except that under the rotten bruckram in the river course near the latter place a dark red sandstone, quite soft in consistency, makes its appearance. This cannot be distinguished in grain and colour from the red sandstone of Heaton Mersey, Beet Bank Bridge, Collyhurst, Sutton, Grimshaw Delph, and Rougham Point, previously described.

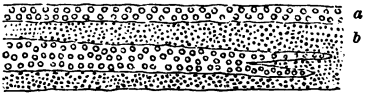
BELAH SCAR SECTION.*



The conglomerates and sandstone extend to Belah Scar, where a fine section of them is seen. Both rocks lie nearly level, but they have evidently a slight inclination to the west-south-west. It is difficult to measure the entire thickness, but it cannot be much less than four hundred feet. At Belah Scar the conglomerate at first sight appears as occupying waterworn hollows in the underlying soft red sandstone, thus—

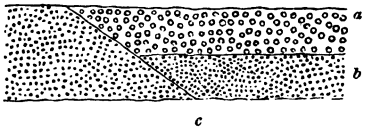


a representing the conglomerate, and *b* the soft red sandstone. But in a short distance the conglomerate appears in the sandstone, thus—



* In this and the following wood cuts I shall use, *a* to denote the conglomerate, and *b* the lower new red sandstone.

And again thus—



c in this wood cut denoting what appears to be either a joint or a slip, I cannot say which positively.

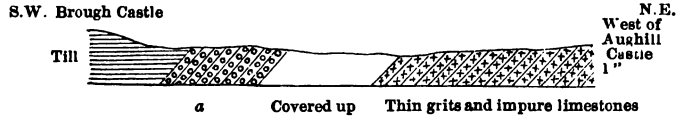
The sandstone appears to extend in an easterly direction up the valley for about a mile, at first nearly level; but certainly increasing a little in its dip, which is to the west-south-west. It is succeeded by a cream-coloured carboniferous limestone, and then a red sandstone, similar to the Smardale sandstone,* appears up to the Foot Bridge over the stream at Whitrigg, where the carboniferous limestone is again seen dipping west-south-west, at an angle of 21°.

The conglomerate in the vicinity of Brough varies considerably from that of Belah Scar, both in extent and position; it is of far greater thickness, and instead of lying nearly level, as it does at the last-named place, it dips at a great angle, as described by Professor Sedgwick, who says:—"And I may here remark, as I have done in a former paper, that the magnesian conglomerates close to Brough have been tilted by the action of the Pennine fault, in the same manner as the carboniferous beds on which they rest, whilst the same conglomerates near Kirkby Stephen rest almost horizontally on the edges of the beds which have been tilted by the action of the Craven fault, and hence we may conclude that the two faults, although both produced near the end of the palæozoic

* For a description of this sandstone lying in the mountain limestone, see Professor Sedgwick's paper on the Lower Palæozoic Rocks at the base of the carboniferous chain, between Ravenstonedale and Ribblesdale. Quarterly Journal of the Geological Society of London, vol. viii., p. 43

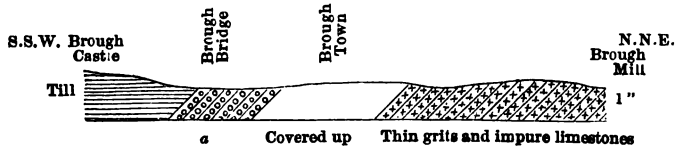
period, were not strictly contemporaneous—the Craven fault being the older of the two."*

AUGHILL SECTION.



Near the hummock of reddish-coloured till, on which the old castle of Brough stands, the Aughill brook joins the Swindells brook. In the bed of the former stream the conglomerate is seen in great thickness; I did not measure it, but I should estimate it at full 300 feet. Under it appear some red sandy beds parted by thin beds of shale, not well exposed, but apparently of a soft nature, and most probably the soft red sandstone of Belah Scar, and then come coarse and brown-coloured girts, which are succeeded by thin limestones. These strata, both permian and carboniferous, dip to the west-south-west at an angle of 46°.

BROUGH SECTION.

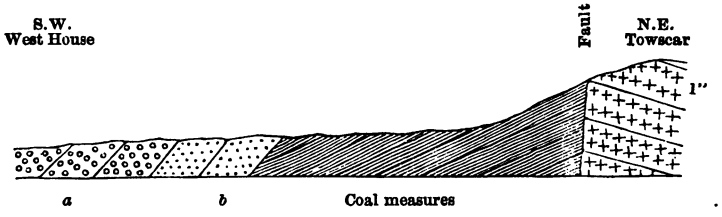


The Brough section is taken from near the junction of the Aughill brook with the Swindells brook, which runs through

* On the Lower Palæozoic Rocks, at the base of the carboniferous chain, between Ravenstonedale and Ribblesdale. By the Rev. A. Sedgwick, F.R.S., G.S., &c. Quarterly Journal of the Geological Society of London, vol. viii., p. 38.

the town up to the mill towards the north-east. At first the conglomerate, similar to that in the Aughill brook but apparently not in quite such great force, is seen dipping to the west-south-west at an angle of 43°; then the strata for a distance of about 250 yards cannot be seen, but in the stream just above the bridge impure limestones and thin bands of red sandstone make their appearance, which dip west-south-west at an angle of 46°. These strata, more or less parted by beds of shale, extend up the valley for above half-a-mile beyond the mill; but the dip is easier, not being more than 27° a little west of the mill. They contain carboniferous limestone fossils. Both permian, and carboniferous strata are here raised at a high angle, and shew that they have been acted upon by the Pennine fault, as noticed by Professor Sedgwick.

West House Section.



After leaving Stenkreth Bridge, and going southwards, little, if any, trace of the permian beds has been met with until you arrive at West House, near Burton-in-Lonsdale, in Yorkshire. I have not examined the district with such care as to speak with certainty on the matter; but I think any considerable breadth of the deposit would not be likely to have escaped the keen and practised eye of Professor Sedgwick. At West House, however, we have the finest section of the conglomerate and lower new red sandstone, whether

we consider the thickness of the beds or the extent of the surface exposed, that I have seen in the north-west of England.

Many years since, Professor John Phillips, in describing the geology of the district, thus alludes to the permian beds here:—

"But at West House, on the line of the road, a curious rock with a southward dip is occasionally exposed in digging the foundations of houses, which resembles in composition the brecciated beds alternating with new red sandstone at Kirkby Stephen and Stenkreth Bridge.

"This stone is a fine grained light coloured red sand, containing a variety of imbedded fragments, more or less rounded, apparently, according to the degree of their hardness. Limestone fragments of gray and red colour, are the most numerous, the largest and the most angular: ironstone in small pieces and in different states of decomposition is plentiful, and a few pebbles (granular slate) of more sandy substance make up the mass, in whose interstices calcareous spar ramifies as in the old red conglomerate of Kirkby Lonsdale. No fossils have been found in it, except what the included limestone fragments contain. It is locally called 'red limestone,' and is occasionally used in building, for which its large thin beds are well adapted. It is unknown, except about West House, where it occupies a considerable surface of red soil."

With the exception of the above description, and the allusion made to the West House deposit by Professor Sedgwick, I am not aware of any information having ever been published on the subject.

In the bed of the Greta, at Burton-in-Lonsdale, the lower coal-field and some parts of the middle coal-field are seen dipping to the east, and near the weir there they incline at an angle of 16°. Between Burton and West House little can

be seen of the strata, owing to the thick covering of drift, but the whole of the coal-field appears to be thrown down to the east to a considerable extent, and in this hollow the permian beds lie.

The conglomerate is first seen in a sawpit near the smithy, at West House, lying apparently almost level. In its appearance it resembles the harder and upper deposit at Kirkby Stephen so much as to be scarcely distinguishable from it, except that in the West House deposit, in addition to the limestone pebbles there are a few of red sandstone and white quartz. The pebbles, some of which are rounded and others angular, are cemented together with a sandy calcareous paste, varying considerably in its hardness.

On proceeding eastwards, up the valley in which flows a small stream called Moregill, a fine series of the beds is seen. The conglomerate at first makes its appearance as a hard reddish-coloured stone, exactly like that seen at the smithy. It dips to the south-west at an angle of 22°; proceeding further up the brook it begins to be separated by beds of fine grained red sand; and at the quarry, were it was formerly wrought for flags, it has a dip of 55° to the south-west, and contains pebbles of red sandstone and white quartz. The conglomerate is seen for some distance further up in the valley, with a dip reaching as high as 60°. I had no means of measuring the thickness of the whole of the conglomerate beds, but they must reach to near 300 feet.

The conglomerate is succeeded by a soft red sandstone of a dark red-colour, with variegated beds towards its base like that seen at Belah and previously described. The former bed appears to pass into the sandstone, and the latter gradually becomes more arenaceous until the pebbles disappear altogether. It dips to the south-west at an angle of 60°. The thickness of it I did not measure; but I estimate it at about 500 feet of red sandstone without any pebbles. At

its base it graduates into a finely laminated red marl. Then come coal-measures, consisting of shales and fine grits, dipping to the south-west at an angle of 35°. Many attempts to work coals appear to have been made here in these strata, but no seams worth working appear to have been met with. Black curly shales like limestone shales then occur, lying nearly level. After going up the hill the third of a mile, over ground covered up, we come to the mountain limestone of Towscar, part of Thornton Fells, which appears to dip to the north-east at an angle of 39°.

Conclusion.

After having given the foregoing particulars of the permian deposits of the north-west of England, which are by no means so ample and satisfactory as I could have wished, I shall conclude by presenting a short summary of them. The beds, with their respective greatest thicknesses, will be found to occur in the following (descending) order:—

	Feet.
1. Red marls with gypsum in the north, and thin beds and nodules of limestone in the south of the district.....	300*
2. Magnesian limestone, resembling the Yorkshire deposit...	10
3. Conglomerate	350
4. Lower new red sandstone, of a soft and crumbling character	500
	1160

Under these beds the purple-coloured sandstone of Whitehaven occurs. This rock I am inclined to class with the coal-measures, rather than include it with the true permian beds. Without, however, including this rock, it will be seen

* I take this thickness from the Scarisbrick section, which I assume to be permian, and not the upper red marls of the trias.

that I have greatly increased the thickness of the permian beds, which in a former paper I only estimated at 330 feet.*

The red marls and gypsum deposits are the highest members of the permian group which I have as yet met with, and although generally dipping in the same direction as the overlying trias beds, are frequently uncomformable to them. This will account for the permian deposits not being so often exposed in natural sections.

The thin ribbon beds of limestone, containing much clay and iron, lying in the lower part of the red marls, as found in South Lancashire in the neighbourhood of Manchester, become thicker and more like the Yorkshire and Durham limestones in grain, colour, and composition, as you proceed towards the north at Stank and Barrow Mouth.

The sandy conglomerate beds, containing rolled pebbles of Hug Bridge, Norbury, Cheetham weirhole, and other places in South Lancashire, appear to gradually pass first into the arenaceous conglomerate of Barrow Mouth, and then into the calcareous conglomerates of Rougham Point, Kirkby Stephen, Brough, and West House. When the deposit is near a coal-field, it is generally arenaceous in character, and when in a limestone district, calcareous; thus shewing that most of the materials composing it were derived from or near the neighbourhood in which it is now found, and not brought from a distance. But certainly the cement in many places has a great resemblance to volcanic ash.†

The conglomerate is generally, but probably not always, unconformable to the lower new red sandstone of Collyhurst, Sutton, Belah, &c., having been often deposited in hollows and on waterworn surfaces of that rock.

* See Author's paper in vol. II. of the Quarterly Journal, previously quoted.

† I am convinced that some of the mottled clays and shales of the upper coal field, as well as many of the permian beds, have a great deal of volcanic ash in their composition,

The soft red sandstone of Heaton Mersey, Beet Bank Bridge, Collyhurst, Sutton, Rougham Point, Belah, and West House, differs so much in its physical characters from the purple-coloured gritstones of Whitehaven lying under the conglomerate of Barrow Mouth, and is so generally absent from the permian beds, that they may be considered as distinct rocks; and hence I am inclined to class the Whitehaven rocks with the purple-coloured carboniferous sandstone of Collyhurst rather than the soft red permian sandstone found at the last named place.

The soft red sandstone and its overlying bed of conglomerate are deposits of far greater extent and importance than they were hitherto supposed to be, and I am convinced that they will prove to be of the same geological age as the red sandstone and conglomerate seen at the Craigs and in the Cleuden near Dumfries. When I first saw the conglomerate bed at the latter places some years since in company with my friend Professor Harkness, it puzzled me much, as being like no trias deposit with which I was acquainted in the north-west of England, and so much resembling some of the permian beds. Professor Harkness has since written on this district.* Sir R. I. Murchison, I believe, was the first

* On the New Red Sandstone of the Southern portion of the Vale of the Nith, by Robert Harkness, Esq. Quarterly Journal of the Geological Society, vol. VI., p. 389, *et seq.* In this article Mr. Harkness describes the Dumfries sandstones as triassic, and at p. 397 of his interesting memoir, admits that the whole of the Dumfries beds are inferior to the sandstone of Annan, containing tracks of the Labyrinthodon, like those of the Cheshire trias. He divides the Dumfries beds into three deposits, viz.:—

	Ft.
"1. Thick bedded sandstones with their overlying flaggy strata..	390
"2. Conglomerate.....	300
"3. Fine grained sandstone covering the conglomerate	300
	990"

The tracks of animals found in the first sandstone are quite different from those found in the trias. When I first saw the conglomerate above the red sandstone at the Craigs quarry, near Dumfries, I was not so well acquainted with the

geologist to suspect the red sandstone and conglomerate of Dumfries to be permian.*

The carboniferous strata appear to have been affected by two distinct periods of disturbance, namely, the first which occurred prior to the formation of the permian beds, as shewn by the hollows and eroded surfaces in and on which the latter now lie and repose in the neighbourhood of Manchester, and at Stenkreth Bridge, Rougham Point, and West House; and the second like those of Norbury, Collyhurst, Patricroft, Bedford, Atherton, Edge Green, Sutton, Barrow Mouth, Aughill, and Brough, which have taken place since the deposition of the permian beds, as is evident from the present position of both formations. Professor Sedgwick remarks, "that the magnesian conglomerates close to Brough, have been tilted by the action of the Pennine fault, in the same manner as the carboniferous beds on which they rest; whilst the same conglomerates near Kirkby Stephen rest almost horizontally on the edges of the beds which have been tilted by the action of the Craven fault; and hence we may conclude that the two faults, although both were produced near the end of the palæozoic period were not strictly contemporaneous—the Craven fault being the older of the two."† These views appear to me not only applicable to the district of Kirkby Stephen and Brough, but also to the greater part of the country described in this paper. The first-named dislocations representing the Craven and the last named the Pennine fault. The great dislocations at Ardwick and Bradford,

permian beds of the north-west of England as I am now, or I should have recognized it immediately as permian. In Mr. Watts' quarry at Craigs, the first sandstone dipped due west at an angle of 36°, whilst the conglomerate appeared to dip to the west at an angle of 7°, so these two beds are not always conformable to each other.

* See his paper on the Silurian Rocks of South Scotland, printed in vol. vii. p. 163, of the Quarterly Journal of the Geological Society.

† Vol. VIII., p. 38, of the Quarterly Journal of the Geological Society.

Pendleton and Patricroft, all appear to be not only of the same age as the Craven fault, but to be fully as great in their displacement of the strata.

In further support of my opinion that the limestones of Collyhurst, Stank, and Barrow Mouth are of the same relative age, although differing so much in appearance and chemical composition, I may state, that in the drift deposits of South Lancashire, the first named only has been found by me; whilst in the drift of North Lancashire and Morecambe Bay the last two only occur; thus shewing that they are not met with together, which we should most probably expect to be the case if they were distinct deposits.

Addendum.

During the passage of the above paper through the press, Mr. Kenworthy's section, described at page 236, has been carried down through the red marls and limestones into the lower new red sandstone. The following beds, therefore, must be added to those previously given, viz.:—

	ft.	in.
Limestone rock, hard and gritty	4	6
Blue earth, or metal	3	1½
Limestone band	0	5
Red earth, very sandy	4	5
Limestone rock, hard	0	9
Red earth	0	1
Limestone band, very hard	0	2½
Red earth, sandy and very hard	1	6½
Brownish red rock, hard and full of water, penetrated	18	9
	33	9½

Probably one of the beds of sandy red earth will be the conglomerate. In the above section 54 beds of limestone are enumerated.

XI.—*On an Apparatus for collecting the Gases from Water and other Liquids, and its Application in general Chemical Analysis.*

By Robert Angus Smith, Ph.D., F.C.S.

[*Read March 6th*, 1855.]

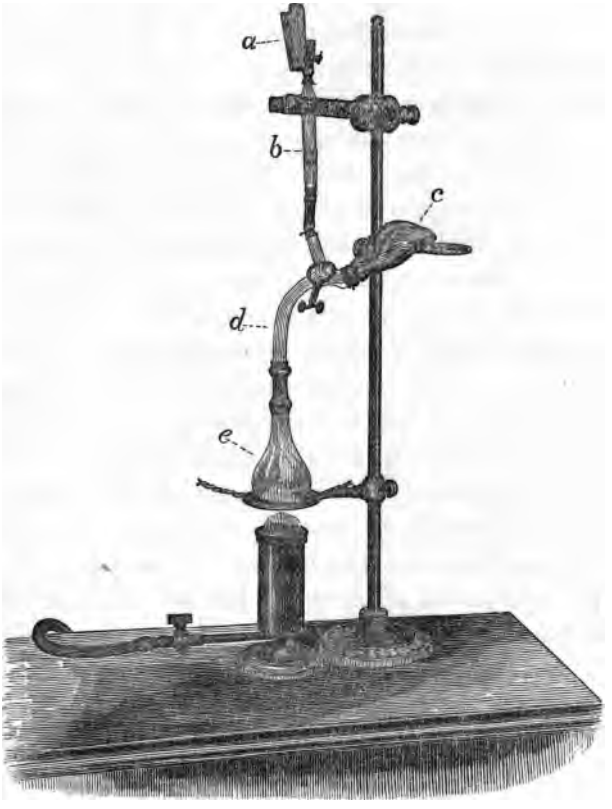
There never has been, to my knowledge, a suitable apparatus for collecting the gases from water. These gases have been collected, but the widely different results of Dalton and Saussure shew how imperfect have been the methods used. The apparatus, not till lately altered, as far as I can understand the description, was simply a retort filled both in the neck and bulb; when heated the water would of course first come from the neck, this being inserted under a receiver, over mercury, would cause first a certain amount of water to rise in the receiver. After some time ebullition would begin, and steam and gas would escape together. The method is in a high degree unpleasant to work with, and the loss is apt to be great, the water that comes over being sufficient to absorb a considerable amount of the gas. Again, there must be so much evaporated that the steam itself, when condensed, will form a large portion of the water that comes over, and the result obtained must, in a great measure, be the difference between the quantity of air absorbed by the water during a long space of time, and the quantity absorbed in a short time by a smaller quantity of water. This absorption must, of necessity, take place when the water over the mercury has cooled.

Professor Bunsen has directed his talents to this, and has improved the plan to a great degree, but I cannot think that he has completely succeeded. As far as I understand his apparatus, as described by Dr. Hoffmann in the Journal of the Chemical Society of London, there is still a great amount of steam carried over with the air, which condensing above the mercury must lead to absorption and to error. In fact, his principle is to carry the air over by a superabundance of watery vapour. Then he makes a globe with all its joints and attachments stand the pressure of the atmosphere, which is of itself a dangerous experiment, so readily do these joints give way and allow air to pass. For these reasons and because of its complicated structure, I have not used the apparatus of that eminent chemist.

One of my earliest trials was the following; it may be useful to describe it, as it will shew what reason I have for avoiding pressure as much as possible. The flask in which the water was boiled was connected by a bent tube with a vessel of mercury, on the upper part of the bend a tube was attached exactly in the manner now used, and which will be seen by the woodcut. When the apparatus was filled with water, and heat applied, the mercury of course yielded and acted like a safety valve. Sometimes, however, it rose too high or sunk too low, and the pressure of a very small column was sufficient to cause air to enter by the joinings, even after they were bound in the most careful manner with strong wire. Another objection was, that over the mercury a certain amount of water was placed, which did not sufficiently diffuse itself amongst the rest, but remained comparatively cool. This might have been avoided by heating the mercury also, had not a readier plan presented itself.

The principal feature of the method adopted is that of regulating the varying pressure which results from boiling, and from the generation or escape of the gases, by a balloon capable of dilatation and contraction. By the use of this

apparatus the pressure within and without the apparatus is always the same, and the apparatus is at the same time kept constantly full.



The flask (*e*) is fitted on to the glass tube (*d*) by a strong tube of vulcanised caoutchouc, bound round firmly with wire, so that no escape of water or gas occurs, although used for weeks together. To the other end of the tube (*d*) is attached a thick balloon of vulcanised caoutchouc (*c*), it may probably be as well to have it thin, but for the sake of convenience, this kind being readily found in the shops, I have used it thick. The small tube at the top is, of course,

one piece with the tube (*d*). The tube (*b*) is a receiver for the gases, and is connected by a flexible tube to the small tube projecting from (*d*). This tube may be disconnected by means of an external pressure valve, or a steel spring, which closes the caoutchouc tube. A similar valve is placed at the upper part of the tube (*b*).

If the balloon be strong and sufficiently elastic, it may be pressed flat, and then allowed to expand, when it will fill itself if the end of the tube has been dipped into any liquid. When raised again into its proper position, the water may be pressed from the balloon into the flask, and up to the point (*a*). The balloon is then empty, or nearly so, and perfectly flat. If it be strong, or if it have a tendency to expand, it may exercise a slight pressure, tending of course to draw air into the joints, but this is very small indeed, and if too much, then a balloon with less elasticity may be used. The joint (*a*) is shut, and that between (*b*) and (*d*) opened. The water is boiled, and the air as it rises passes into the upper tube (*b*). The balloon (*c*) is constantly expanding and contracting to a small extent. The hot water is continually rising, but has no injurious effect on the balloon. It is important not to allow it to hang down, as cold water may lodge in it. The apparatus is small, holding about 3,300 grains of water. Much less may in reality be used with safety. The tube (*d*) is wide, of about $\frac{3}{4}$in. bore, and so is more readily kept at a high heat during the process. When no more air escapes the connecting valve is shut, the tube (*b*) removed, and the gas passed into a graduated tube over mercury for measurement and analysis.

When the gas fills (*b*), there is little fear of loss by absorption. This absorption may be calculated, or it may be entirely prevented by completely separating the gas from the water. This is done by putting a piece of paraffine into the tube; it melts, swims on the top, and on cooling prevents all connection between the water and the air or gas in (*b*). Paraf-

fine does not hold very firmly to the glass, and if used a large piece must be taken, but if a mixture of one-half paraffine and one-half wax be used, then a very little will be found enough to sustain the pressure when passing the gas through mercury into the graduated tubes. The end (*a*) might have a stopcock of glass and the tube (*b*) might be graduated, but I do not at present see many advantages in that change, except under exceptional circumstances. If the tube (*b*) should be long, it may happen that paraffine will not melt in it until the surface of the water be a good deal lowered, in that case either a shorter and wider tube may be used, or if a great amount of gas be expected the long one may be retained, and the melting of the paraffine assisted at first by the application of a lamp. Very little help is required in any case.

On examining waters I find it useful to adopt this process as a regular part of the analysis. As I intend to give a separate paper on the amount of gas contained in waters, I shall say little about it at present, but may mention to shew the importance of the subject that whilst a given portion of the Manchester pipe water gave half a cubic inch of oxygen gas, the same amount of water from a well near my laboratory, polluted by town drainage, gave only .025 of a cubic inch, or in the proportion of 50 to $2\frac{1}{2}$, shewing how thoroughly the organic matter had exhausted the soil of its oxygen.

As the process of collecting gases from water becomes by this means perfectly simple, the apparatus may be employed in many cases of the kind not here mentioned. For example, the amount of carbonates in water may be obtained in this way with great exactness, by simply adding some muriatic acid to the upper receiver and boiling as described, after the free gases have been removed.

Sometimes hydrogen may be collected in this way from dissolving metals, and estimated with advantage, instead of

the direct estimation of the metal when there is a complicated mixture.

Some years ago there was read to the Royal Society a paper of mine on the mode of estimating ammonia, cyanogen, urea, &c., by means of the nitrogen obtained, or decomposing them with chloride of lime or soda. This apparatus gives the power of completing the process, and obtaining much finer results. If even very small quantities are used with this apparatus a correct result may be obtained. If chloride of lime is used it is well not to take too much, as the oxygen given out on boiling must afterwards be absorbed. Water which has been carefully boiled must be used to fill the apparatus.

Sometimes gases may be collected from liquids by the use of a simpler apparatus still. The flask of water may have over it a cup of oil, into the lower part of which the mouth of the flask projects. Over this mouth may be placed a receiving tube, filled with oil or melted paraffine. When the water boils, all the gas goes directly into the tube, and is immediately cut off from the water below. There are cases in which this may be used with advantage, but in general I prefer the apparatus above described.

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John Kennedy ..... April 29th, 1808
John Lawson Kennedy ..... January 27th, 1852
James Kershaw, jun. ..... January 24th, 1854

Richard Lane ..... April 26th, 1822
William Langton..... April 30th, 1830
John Rowson Lingard..... January 26th, 1847

	DATE OF ELECTION.
Thomas Littler	January 27th, 1825
Joseph Lockett	October 29th, 1839
Benjamin Love	April 19th, 1842
Joseph Leese, jun.	April 30th, 1850
Edward Lund	April 30th, 1850
Isaac Waithman Long, F.R.A.S.	January 27th, 1852
George Cliffe Lowe	January 24th, 1854
George T. Lund	January 23rd, 1855
James M'Connel	October 30th, 1829
William M'Connel	April 17th, 1838
John Macfarlane	January 24th, 1823
Edward William Makinson, M.A.	October 20th, 1846
Alexander M'Dougall	April 30th, 1844
The Right Rev. the Lord Bishop of Manchester, D.D., F.R.S., F.G.S.	April 17th, 1849
Robert Manners Mann	January 27th, 1846
Thomas Mellor	January 25th, 1842
William Mellor	January 27th, 1837
John Moore, F.L.S.	January 27th, 1815
David Morris	January 23rd, 1849
Alfred Neild	January 25th, 1848
William Neild	April 26th, 1822
John Ashton Nicholls, F.R.A.S.	January 21st, 1845
William Nicholson	January 26th, 1827
James Emanual Nelson	January 27th, 1852
Thomas Henry Nevill	February 7th, 1854
Edward Byron Noden	October 31st, 1854
Henry Mere Ormerod	April 30th, 1844
John Owen	April 30th, 1839
George Parr	April 30th, 1844
John Parry	April 26th, 1833
George Peel, M. Inst. C.E.	April 15th, 1841
Henry Davis Pochin	January 24th, 1854
Archibald Prentice	January 22nd, 1819
Joseph Atkinson Ransome, F.R.C.S.	April 29th, 1836
Thomas Ransome	January 26th, 1847
John Ramsbottom	February 7th, 1854
Richard Roberts, M. Inst. C.E.	January 18th, 1823

	DATE OF ELECTION.
Samuel Robinson	January 25th, 1822
Alan Royle	January 25th, 1842
Samuel Salt	April 18th, 1848
Michael Satterthwaite, M.D.	January 26th, 1847
Edward Schunck, Ph. D., F.R S.	January 25th, 1842
John Sharp	October 28th, 1824
John Shuttleworth	October 30th, 1835
Joseph Sidebotham	April 20th, 1852
George S. Fereday Smith, M.A., F.G.S.	January 26th, 1838
Robert Angus Smith, Ph. D., F.C.S.	April 29th, 1845
Edward Stephens, M.D.	January 24th, 1834
Alexander J. Scott, M.A., Principal of Owens College	February 7th, 1854
Peter Spence	April 29th, 1851
Edmund Hamilton Sharp	January 23rd, 1855
Archibald Sandeman, M A., Owens College	April 29th, 1851
Thomas Standring	January 27th, 1852
James Stephens	April 20th, 1847
Daniel Stone, jun., F.C.S.	January 22nd, 1849
Robert Stuart	January 21st, 1814
David Thom	April 20th, 1852
James Aspinal Turner	April 29th, 1836
Thomas Turner, F.R.C.S.	April 19th, 1821
James Thompson	April 18th, 1854
Absalom Watkin	January 24th, 1823
Joseph Whitworth	January 22nd, 1832
George Bencroft Withington	January 21st, 1851
William Rayner Wood	January 22nd, 1839
George Woodhead	April 21st, 1846
Edward Woods	April 30th, 1839
Robert Worthington, F.R.A.S.	April 28th, 1840
James Woolley	November 15th, 1842
William Crawford Williamson, F.R.S., Owens College	April 29th, 1851
Samuel Walker Williamson	April 19th, 1853

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General Sir Thomas Makdougall Brisbane, Bart., F.R.S., Hon. M.R.I.A., Instit. Nat. Sc. Paris. Corresp., &c., *Makerstoun, Kelso.*

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Eilert Mitscherlich, *Berlin.*

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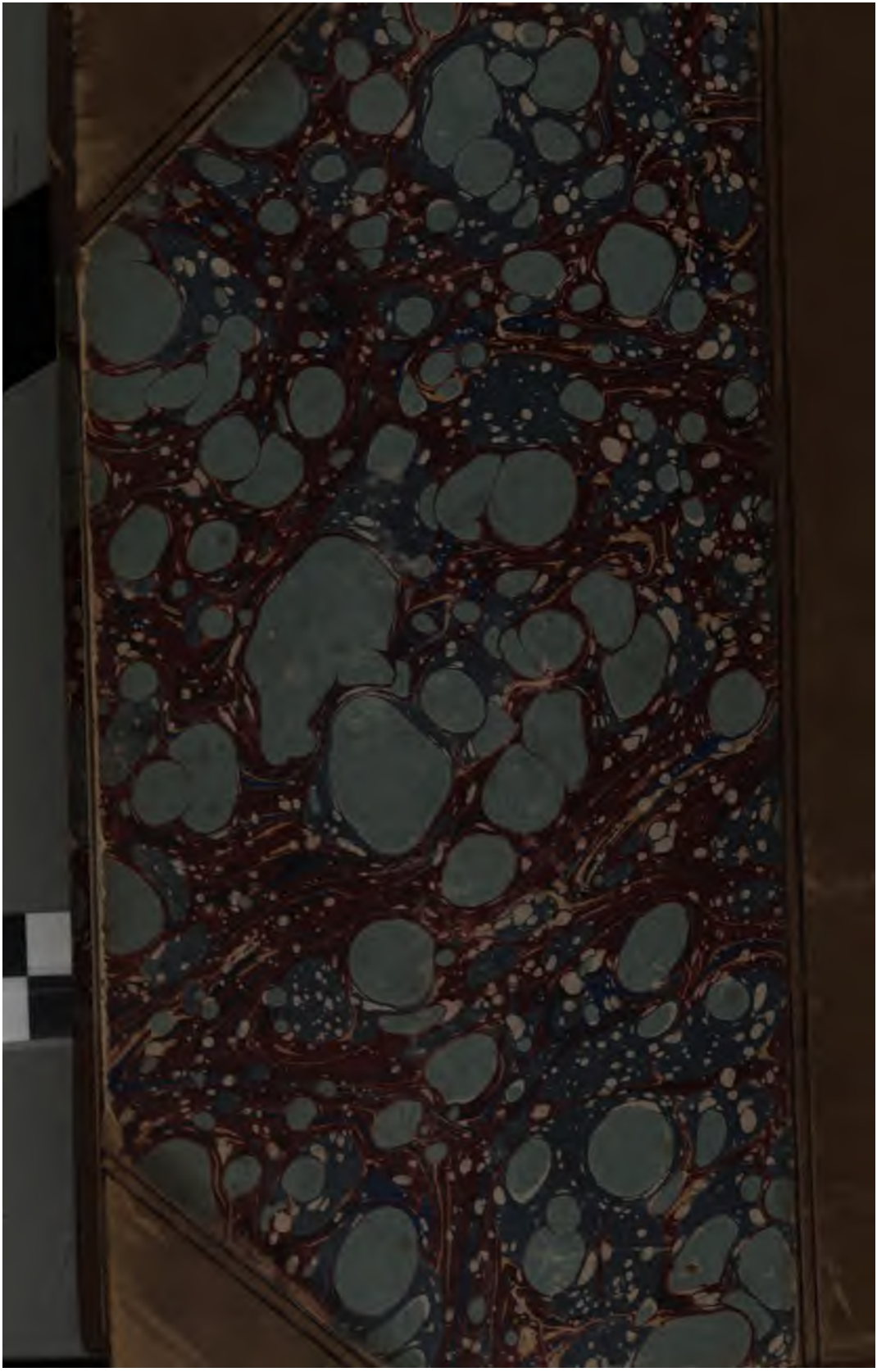
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